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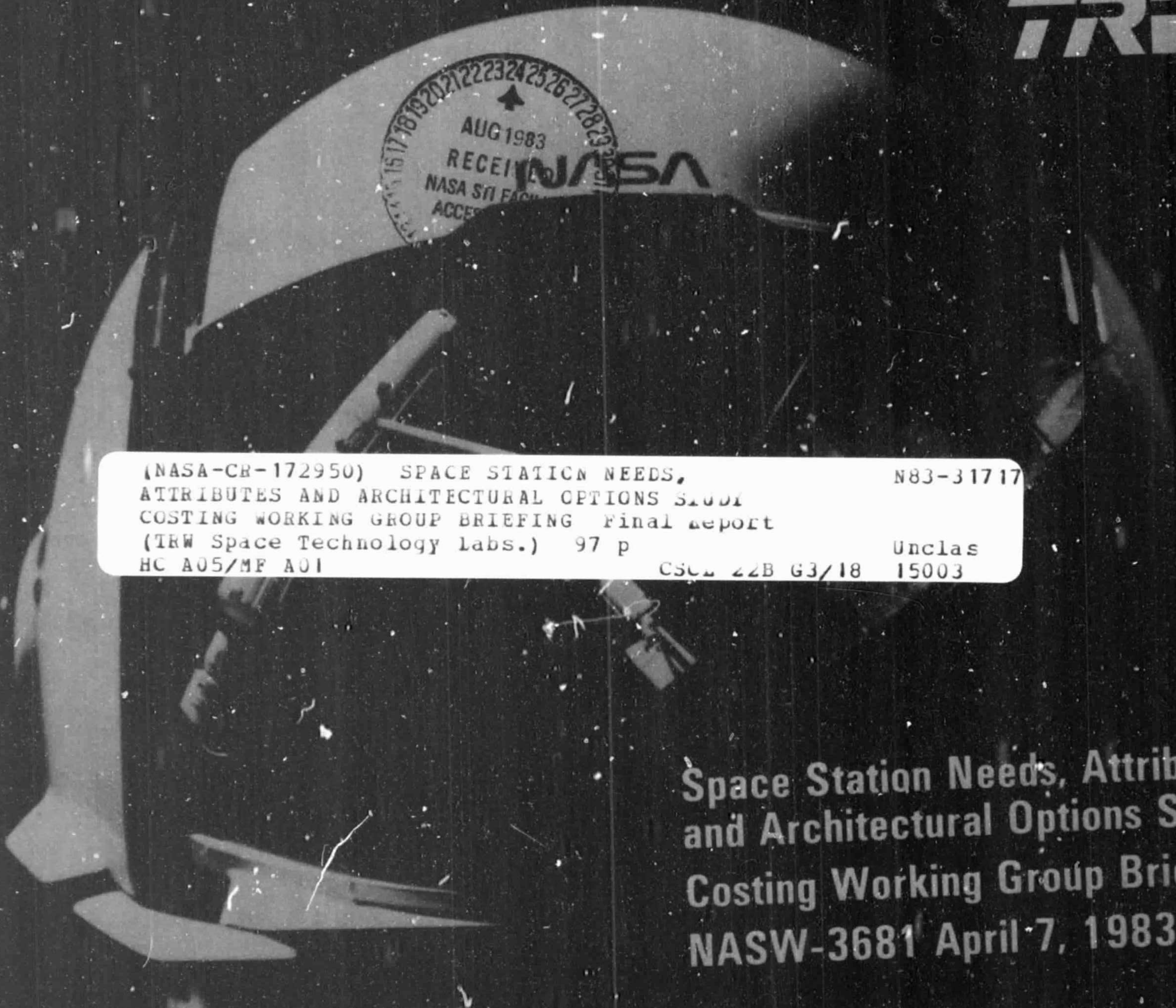

(NASA-CR-172950) SPACE STATION NEEDS, ATTRIBUTES AND ARCHITECTURAL OPTIONS STUDY COSTING WORKING GROUP BRIEFING Final Report (TRW Space Technology Labs.) 97 p HC A05/MF A01 CSCL 22B G3/18 N83-31717 Unclas 15003

Space Station Needs, Attributes and Architectural Options Study

Costing Working Group Briefing

NASW-3681 April 7, 1983

Program Management Division
TRW Space &
Technology Group

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Space Station Needs, Attributes and Architectural Options Study

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AGENDA

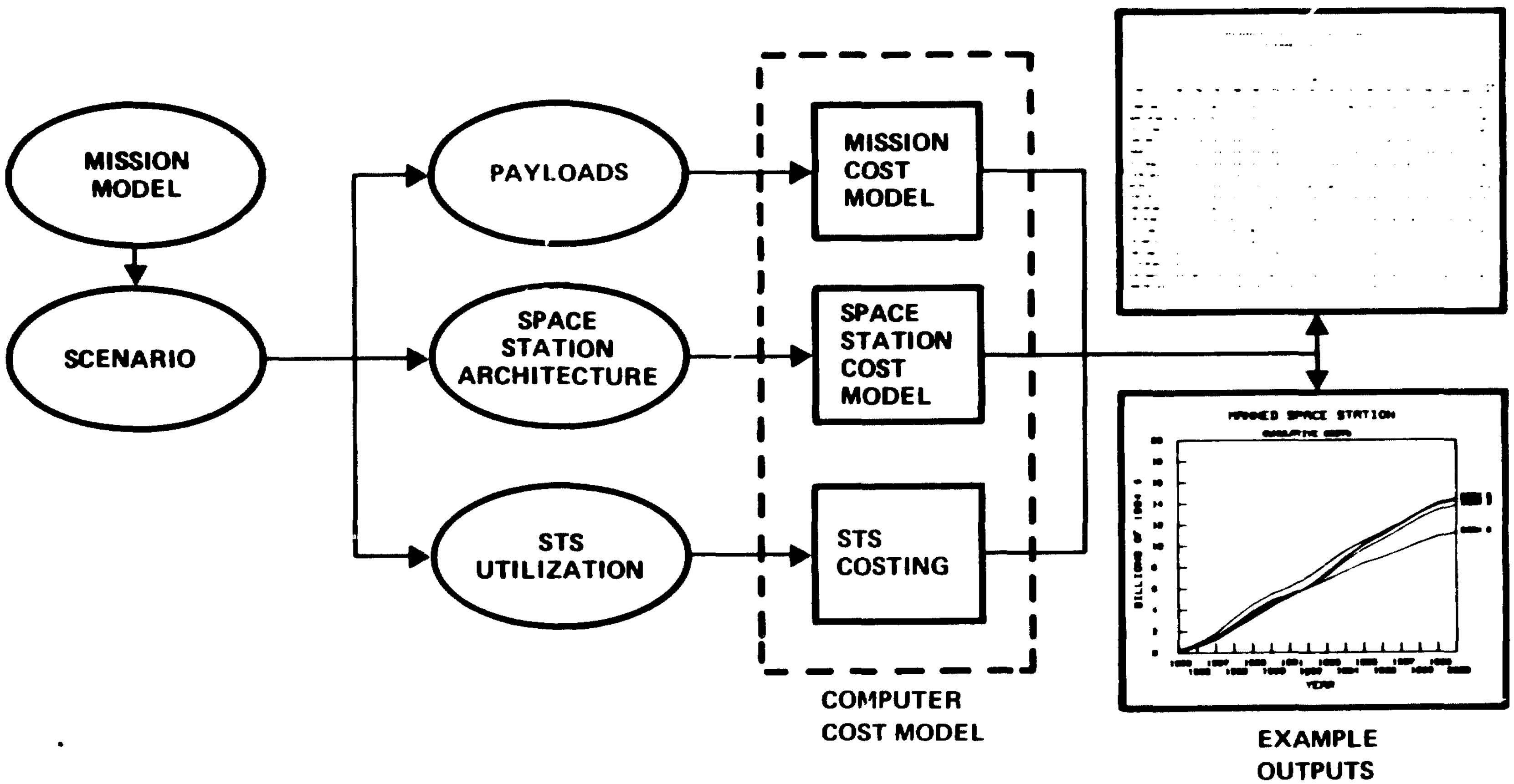
- COST MODELING APPROACH
- COMPUTER PROGRAM
- COST ESTIMATING RELATIONSHIPS
- COST SUMMARY BY SCENARIO
- COST BENEFIT ASSESSMENT
- SUMMARY

Cost Modeling Approach

SS COST MODELING STUDY APPROACH

This chart depicts the interface between tasks and the sequence of information flow. Task 1 developed the Mission Model and the requirements of each mission. These requirements along with the Mission Model schedule resulted in a further definition of the mission payloads, the Space Station architecture and the STS requirements as developed by Task 2 of the study. This information was then used to estimate the cost parameters necessary to generate cost estimates for the system with the aid of cost models for the Missions, Space Station and Space Transportation.

SS COST MODELING STUDY APPROACH



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SPACE STATION WORK BREAKDOWN STRUCTURE

This work breakdown structure (WBS) was used to organize the cost data generated for the Space Station system. An "Evolutionary Scenario" represents all assumed space activities in the years 1985 - 2000. The Space Station portion of that scenario is contained in the Space Segment, Ground Segment, System Level Management and Integration and Space Transportation portions of the WBS. All missions and their deployment are separately accounted for. Product oriented detail has been specified to the module level within the Space and Ground Segments.

It will be seen that the study considers economic benefits to be cost savings in the mission leg of the WBS. These benefits are compared to the Space Station cost previously defined.

SPACE STATION WORK BREAKDOWN STRUCTURE

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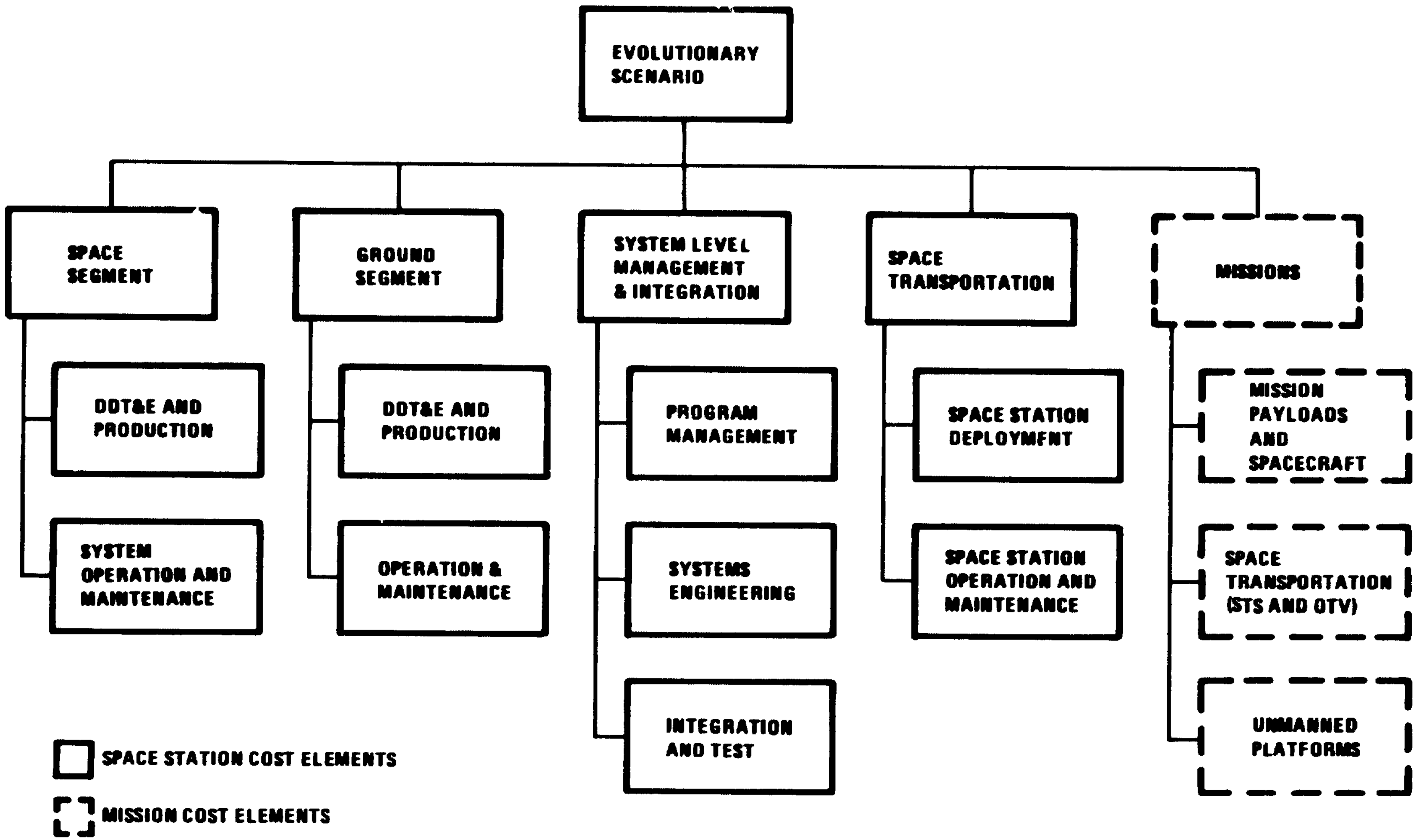


COSTS WERE DEVELOPED AT WBS LEVEL 4

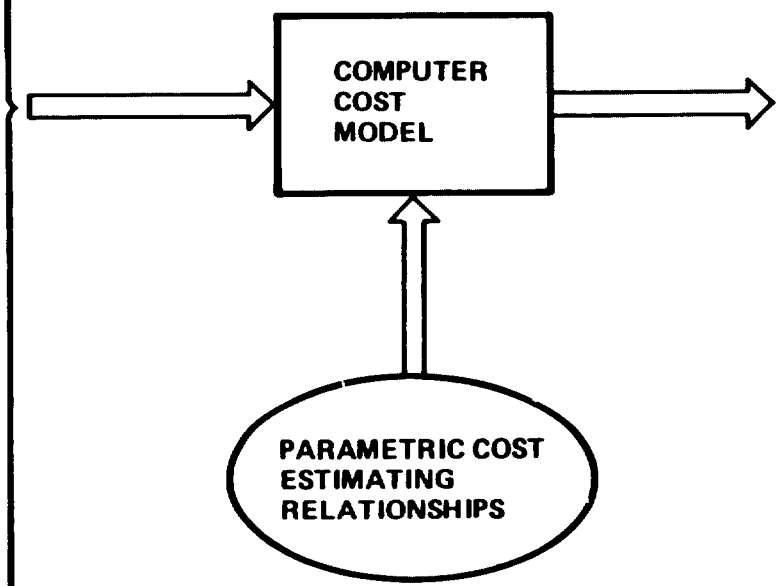
COST MODELING APPROACH

The cost modeling approach consists of utilizing a computer program that is driven by Mission and Space Station definitions and derived parametric cost estimating relationships. The input data required include specific hardware definitions at the Module level and the sequence of activities related to each Module. The computer program require cost estimating relationships for each Module (DDT&E and first unit) as a function of a parameter such as weight. The computer program output includes the cost for each Module, the sum total for development, production and operations/maintenance and the time phased distribution of costs by Module and for the total.

COST MODELING APPROACH

TRW

- MISSION MODEL
  - PROGRAM SEQUENCE OF EVENTS
  - PAYLOAD/SPACECRAFT WEIGHTS, COST CATEGORY AND QUANTITY
- UNMANNED PLATFORMS
  - SEQUENCE OF REQUIREMENTS
  - WEIGHTS AND QUANTITY
- SPACE STATION
  - SEQUENCE OF EVENTS
  - MODULE WEIGHTS, COMPLEXITY AND QUANTITY
- TRANSPORTATION
  - COST PER FLIGHT
  - SEQUENCE OF REQUIREMENTS



- MISSION COSTS
- SPACE STATION COSTS
  - BY ELEMENT
  - DDT&E COSTS
  - PRODUCTION COSTS
  - O&M COSTS
  - SPREAD OVER TIME BY ELEMENT
- STS COSTS
- UNMANNED PLATFORM COSTS
- TIME PHASED TOTAL COSTS

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Computer Program

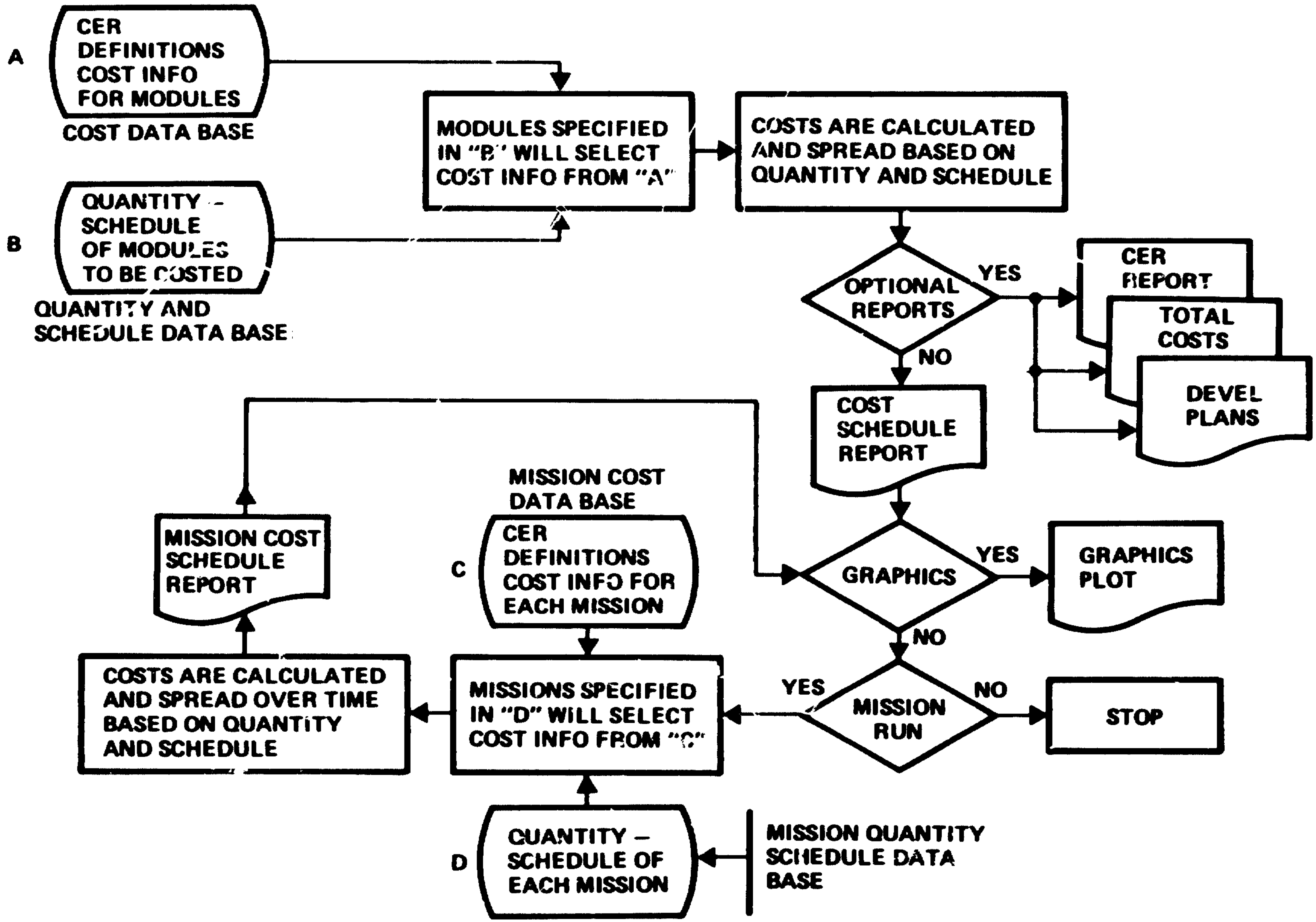
SPACE STATION AND MISSION COST COMPUTER MODEL

The Space Station Model contains two data bases. Data Base "A" contains all the modules that could be used by a space station and the cost estimating relationships (CER) for development and production costs, the weight, operations and maintenance costs relationships plus data relevant to the module. Data Base "B" contains the quantity and schedule of modules to be used for a particular space station scenario. The computer program searches Data Base "A" for the modules specified in Data Base "B" and combines all the data. The program then computes the costs for each module and spreads the cost per the schedule defined in Data Base "B".

The user has a choice of three optional reports. They are the Cost Estimating Relationship Report which prints out Data Base "A" in easily readable form for a check of the data base. The second report is a Total Cost Report that provides total costs by DDT&E, Production and O&M for each module specified in Data Base "B". A fourth report that is not optional is a Cost Schedule Report showing the cost for each module on a yearly basis (1985 - 2000). The report totals each year and provides a cumulative total yearly as well as totals by DDT&E, Production and O&M.

Plotting capabilities are also included. A graphic plot of the yearly costs may be produced from the Cost Schedule Report. The program will also compute Mission Model costs. The same logic is used as in the Space Station Model with similar data bases (data bases C and D). Costs are computed based on quantities and schedules with the defined cost estimating relationships for DDT&E, Production and O&M. The Mission Cost Report and graphics are similar to the space station output.

SPACE STATION AND MISSION COST COMPUTER MODEL



COSTING LOGIC FOR THE SPACE STATION MODEL

For each space station module, cost estimating relationships (CER) were developed based upon module weight as the cost driver. The complexity of the module determines the specific CER to be used. How these relationships were derived is explained later in the presentation. Operations and Maintenance costs are based on a percentage of the production costs. After total DDT&E and Production costs have been calculated for a module, the costs are spread over 2, 3 or 4 years, depending on the user input provided in Data Base "A". Costs are spread using a simple OGIVE curve (i.e., 25% first year, 50% second year and 25% third year for a three year spread, etc.). O&M starts the same year as production is completed. Each time another unit is produced, the O&M is increased a like amount. A 90% learning curve is used whenever more than one unit is produced at one time.

The example shown in the chart provides a hypothetical module with development (D), production (P), launches (L) and operations and maintenance (O&M) taking place over an eleven year period. The example indicates DDT&E costs taking place over two periods followed by launches. The O&M is shown to occur for the first production unit between year 5 and 11 while the O&M for the second unit begins in year 10. The "OO" indicates O&M for two units.

COSTING LOGIC FOR SPACE STATION MODEL

DDTE COSTS = F (WT, COMPLEXITY)

PROD COSTS = F (WT, COMPLEXITY)

O&M COSTS = PERCENTAGE OF PRC⌣UCTION COSTS

$\Bigg\}$ FOR EACH MODULE

YEARS

	1	2	3	4	5	6	7	8	9	10	11
DDTE COSTS	D	D	D								
PROD COSTS			P	P	P			P	P	P	
LAUNCH					L					L	
O&M					0	0	0	0	0	00	00

SINGLE UNIT – NO LEARNING CURVE

MORE THAN ONE – USE LEARNING CURVE

LAUNCH COSTS ARE DIRECT INPUTS.

COST LOGIC FOR THE MISSION MODEL

There are twelve cost categories as defined on the facing page. A cost category has been assigned to each mission. In Data Base "C", cost estimating relationships have been derived for each cost category with weight as the cost parameter. An O&M cost based on yearly ground station costs has been assigned for each cost category. Total costs for DDT&E and production for each mission are then calculated and spread over three years for DDT&E and two years for production. The DDT&E cost is spread over an OGIVE CURVE as previously explained. The production cost is spread evenly over the two year period. In the year production is completed, O&M costs start for that mission and continue to the end of the program. Annual O&M is a constant for any mission and is independent of the number of missions.

COSTING LOGIC FOR MISSION MODEL

DDTE COSTS = F (WT, COMPLEXITY)
PRODUCTION COSTS = F (WT, COMPLEXITY)
O&M COSTS = YEARLY GROUND STATION COSTS
} FOR EACH COST CATEGORY

COST CATEGORIES FOR GENERIC MISSION TYPES

1. FREE FLYER
2. SPACECRAFT
3. PLANETARY-OBSERVER
4. PLANETARY-VOYAGER
5. SPACELAB-PALLET
6. SPACELAB-RACK
7. ASSEMBLED-INSTR
8. COMSAT
9. COM-PLATFORM
10. GEN-EQUIPMENT
11. LOGISTICS
12. MATERIALS FACTORY

COSTS ARE SPREAD AS FOLLOWS:

5 OR LESS UNITS = 2 YEARS
OVER 5 UNITS = 3 YEARS

90% LEARNING CURVE RULES

SINGLE UNIT – NO LEARNING
ONE TO FIVE – USE 90% LEARNING
OVER FIVE – KEEP LEARNING TO FIVE REGARDLESS OF QUANTITY

SAMPLE PRINTOUT
FROM SPACE STATION COST MODEL

This computer printout provides the detailed CER information for each space station module including the cost parameter, the CER constants and other information that may be necessary to determine costs. For example, the resource module has a CER type of 2 indicating a CER represented by a power function of the unit of measure (UNIT MEAS) P, that is, AP^b. P stands for weight in pounds. The measure (MEAS) is the total weight of 27,000 lbs. FACT DDT&E and FACT PROD are the constants A for the DDT&E and first unit CER's while EXP DDT&E and EXP PROD are the exponents for the CER's.

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SAMPLE PRINTOUT FROM SPACE STATION COST MODEL

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SCENARIO SAMPLE

	ELEMENT	CER TYPE	UNIT MEAS	MEAS	FACT DDTE	FACT PROD	EXP DDTE	EXP PROD	LIFE YRS
RM	RESOURCE MOD	2	P	27000	5827.00	1890.00	-.620	-.527	11
HM	HABIT MOD	2	P	37242	2044.00	4088.00	-.575	-.575	11
LM	LOGISTICS MOD	2	P	13900	5827.00	1890.00	-.620	-.527	11
TM	TUNNEL MOD	2	P	5400	1700.00	681.00	-.620	-.527	1
HNG	HANGARS	2	P	5000	1200.00	200.00	-.620	-.450	
CTM	CRYO STORAGE	2	P	15000	1200.00	200.00	-.620	-.450	
AAP	ASSEMBLY AREA	2	P	1000	1200.00	200.00	-.620	-.450	
MLM	MANNED LAB MOD	2	P	30100	48546.00	4088.00	-.727	-.575	
OTVS	OTV SUPPORT	1	P	1000	20.00	8.00	0.000	0.000	
TMSS	TMS SUPPORT	1	P	1000	20.00	8.00	0.000	0.000	
STS	SHUTTLE	0	M	0	0.00	86.00	0.000	0.000	
ASTS	AUGMENTED STS	0	M	0	0.00	90.00	0.000	0.000	
SSTS	SUPER STS	0	M	0	136.00	140.00	0.000	0.000	
LAU	LAUNCH COST	0	M	0	0.00	86.00	0.000	0.000	
SHM	SHORT HAB MOD	2	P	26347	2044.00	4088.00	-.575	-.5	
JM	JUNCTION MOD	2	P	9000	5827.00	1890.00	-.620		
ALM	AIRLOCK MOD	2	P	650	5827.00	1890.00	-.620		
PAM	PORT ADAPTER	2	P	300	1700.00	681.00	-.620		
STM	SHORT TUNNEL	2	P	350	600.00	101.00	-.620		
EA	EXTENSION ARM	2	P	100	600.00	101.00	-.620		
RMS	REMOTE MANIP.	2	P	1000	5827.00	1890.00	-.620		
HPA	HANDL POSIT AID	2	P	650	5827.00	1890.00	-.620		
LBM	LONG BOOM	2	P	700	600.00	101.00	-.620		
SBM	SHORT BOOM	2	P	350	600.00	101.00	-.62		
BJM	BOOM JUNCT	2	P	350	1200.00	200.00			
CM	COMMAND MOD	2	P	800	5827.00	1890.00			
RBM	REBOOST MOD	2	P	1100	1200.00	200.00			
MTT	MOBILE TRANSP	2		550	[illegible]	1890			

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SAMPLE PRINTOUT
FROM SPACE STATION COST MODEL

This cost printout for the space station details the costs for each module as a result of the CER computations using weight, quantity and period of operations. This includes development costs, first unit costs, total production costs, yearly O&M costs, total costs and discounted costs. The total cost shown will include consideration for production breaks.

SAMPLE PRINTOUT FROM SPACE STATION COST MODEL

SPACE STATION MODEL

COSTS IN MILLIONS SCENARIO : SAMPLE

WBS	ELEMENT	YRS LIFE	DDTE	FIRST UNIT	QTY	PROD COST	O & M COST	LAUNCH COST	TOTAL COST	DISCOUNTED COST
RM	RESOURCE MOD	11	281.425	235.775	3	652.095	13.042	0.000	1097.431	1013.177
HM	HABIT MOD	11	179.131	358.261	2	680.696	13.614	0.000	984.144	835.614
LM	LOGISTICS MOD	11	218.671	172.230	3	476.345	9.527	0.000	802.040	509.355
TM	TUNNEL MOD	11	44.541	39.680	4	143.244	2.865	0.000	221.882	221.423
HNG	HANGARS	11	30.534	21.650	1	21.650	.217	0.000	52.618	54.207
CTM	CRYO STORAGE	11	46.355	39.617	1	39.617	.792	0.000	90.726	93.[illegible]
AAP	ASSEMBLY AREA	11	16.565	8.934	2	16.974	.170	0.000	35.960	
MLM	MANNED LAB MOD	11	810.592	327.267	1	327.267	6.545	0.000	1209.857	
LAU	LAUNCH COST	20	0.000	0.000	0	0.000	0.000	0.000	0.000	
SHM	SHORT HAB MOD	11	154.629	309.258	3	855.334	17.107	0.000		
JM	JUNCTION MOD	11	185.378	140.223	2	266.423	5.328	0.[illegible]		
ALM	AIRLOCK MOD	11	68.289	40.455	5	179.562	3.[illegible]			
PAM	PORT ADAPTER	11	14.851	10.112	6	53.137				
STM	SHORT TUNNEL	11	5.558	2.533	4					

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SAMPLE PRINTOUT
FROM SPACE STATION COST MODEL

This schedule output indicates the type of activity involving a particular module during any year, i.e., development, production, launch or O&M.

SAMPLE PRINTOUT FROM SPACE STATION COST MODEL

TRW

MANNED SPACE STATION SCHEDULE

SCENARIO SAMPLE

D= DEVELOPMENT P= PRODUCTION L= LAUNCH O= OPERATIONS & MAINTENANCE

SCENARIO	QTY	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
RESOURCE MOD	3			D	D	DP	P10	10	P10	P20	P20	P30	30
HABIT MOD	2				D	D	DP	DP	DP	PPO	PO	PO	POO
LOGISTICS MOD	3	D	D	D	DP	P	PO	O	PO	PO	POO	OO	POO
TUNNEL MOD	4						D	D	DP	DPP10	PP20	[illegible]30	P40
HANGARS	1												
CRYO STORAGE	1							D	D	DP	DP	PO	
ASSEMBLY AREA	2		D	D	D	P	PO	O	O	PO	POO		
MANNED LAB MOD	1	D	D	DP	DP	DP	PO	O	O	O	O		
LAUNCH COST	0					0L	0L	0L	0L	0L	0L		
SHORT HAB MOD	3		D	D	DP	DP	PPO	PO	PPOO	POO			
JUNCTION MOD	2		D	DP	DP	DP	PPO	PO	PO	POO			
AIRLOCK MOD	5		D	D	D	2P	2P20	20	20	2P2			
PORT ADAPTER	6			D	D	D3P	3P30	30	30				

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SAMPLE PRINTOUT FROM SPACE STATION COST MODEL

This cost spread format permits an evaluation of the contribution of each module to the total system annual costs. It enables the analyst to make adjustments to development or production schedules in order to meet funding requirement constraints or targets.

MANNED SPACE STATION COSTS

SCENARIO SAMPLE

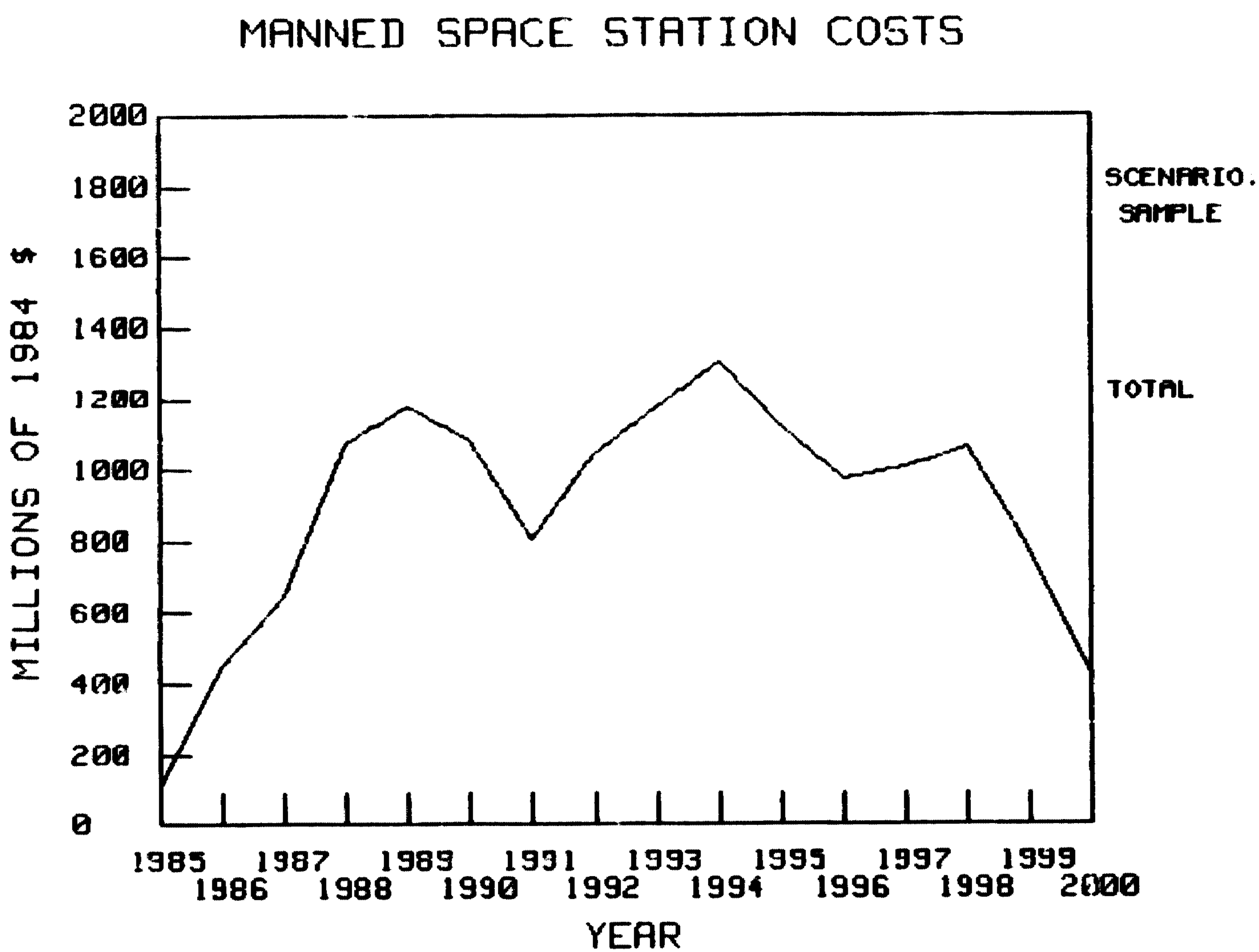
(Costs in Millions of 1984 Dollars)

	YEAR												
SCENARIO	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
RESOURCE MOD	0.0	0.0	84.4	112.6	202.3	122.2	4.3	122.2	126.6	126.6	130.9	13.0	
HABIT MOD	0.0	0.0	0.0	17.9	44.8	107.5	188.1	125.4	114.3	150.1	114.3	67.4	
LOGISTICS MOD	32.8	87.5	65.6	84.5	68.9	54.8	3.2	54.8	72.1	58.0	6.4	58.0	
TUNNEL MOD	0.0	0.0	0.0	0.0	0.0	6.7	17.8	33.2	47.1	41.1	41.8	22.7	
HANGARS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
CRYO STORAGE	0.0	0.0	0.0	0.0	0.0	0.0	7.0	18.5	25.8	22.8	12.7		
ASSEMBLY AREA	0.0	5.0	6.6	5.0	4.5	4.6	.1	.1	4.6	4.6	.2		
MANNED LAB MOD	81.1	202.6	292.3	333.6	179.2	55.6	6.5	6.5	6.5	6.5			
LAUNCH COST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
SHORT HAB MOD	0.0	23.2	61.9	139.2	146.9	191.3	129.4	197.0					
JUNCTION MOD	0.0	27.8	95.2	111.7	69.9	44.7							

SAMPLE PRINTOUT
FROM SPACE STATION COST MODEL

This graphical display from the computer program permits an evaluation of the spending profile for any system architecture with a plot of total annual costs vs. time. Cumulative cost printouts are also available.

SAMPLE PRINTOUT FROM SPACE STATION COST MODEL



Cost Estimating Relationships

SS COST MODEL COMPARISONS

Space Station cost modeling made use of a wide range of cost analysis resources. TRW's space system cost experience was implemented through analogy, cost estimating relationships (CER's) and the RCA PRICE model, which includes a platform variable that allows the assessment of man-rated space hardware.

Our Cost Benefits Analysis Review Board provided data and advice on both costs and benefits. Board participation was as follows:

* General Research Corporation: Dr. E.N. Dodson
* Planning Research Corporation: Mr. C. Bloomquist
* Science Applications, Inc.: Dr. B. O'Leary

In addition, general aerospace industry experience was made use of, especially through the vehicle of the Johnson Space Center Cost Model.

The primary output of this process was a module level cost estimating methodology that generates Space Station costs as a function of weight and complexity.

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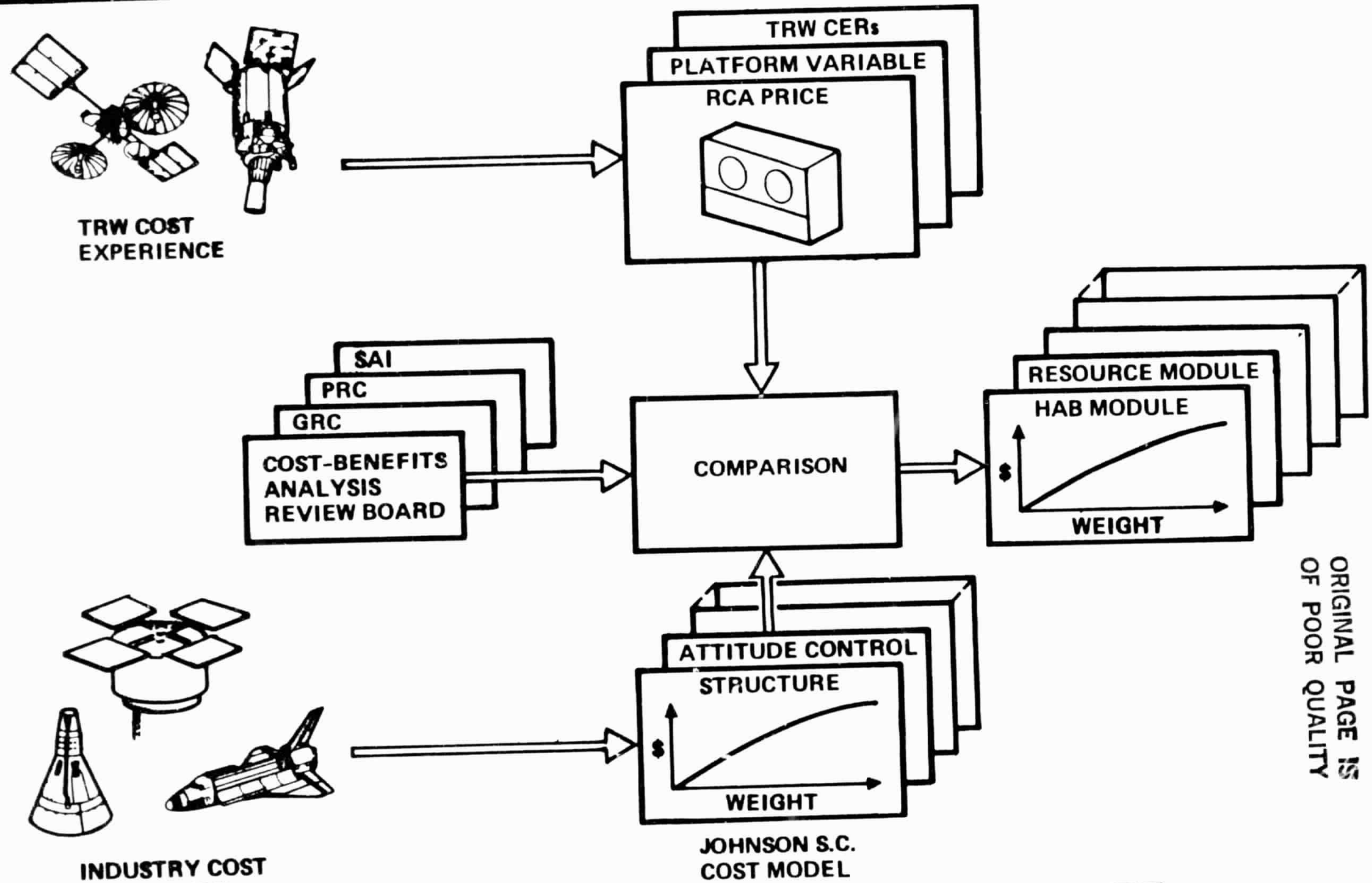
SS COST MODEL COMPARISONS



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COST REASONABLENESS ESTABLISHED BY COMPARATIVE ANALYSIS

DATA BASE FOR COST ESTIMATING RELATIONSHIPS

Cost estimating relationships (CER's) developed for this study are based upon TRW's experience in building spacecraft and studies in which TRW developed detailed cost information. TRW used the help of its consultants and the RCA PRICE model. The chart indicates a list of the programs and sources from which CER's were developed.

DATA BASE FOR COST ESTIMATING RELATIONSHIPS

- **TRW PROGRAMS – SPACE PLATFORM**
  - **TDRSS**
  - **FLTSATCOM**
  - **DSCS II**
  - **MILSTAR**
  - **PIONEER**
  - **HEAO**
  - **INTELSAT III**
- **OTHER**
  - **SPACELAB**
  - **RCA PRICE "BOOK" VALUES**
  - **JSC COST MODEL**

GROUND RULES AND ASSUMPTIONS

These ground rules and assumptions characterize the cost data shown in the following charts. Costs are presented in constant 1984 dollars with learning taken at the 90% level on most multiple procurements. The Space Station new start year is assumed to be 1985 (i.e., FY 1986).

A low level of technological risk is assumed in the Space Station concept. The first habitable module (most likely the Manned Laboratory) is prototyped, the prototype being maintained as a ground test module for operational support. Subsequent habitable modules are adaptions of the first, and as such their DDT&E costs are substantially reduced. Non-habitable modules are assumed to be developed using the protoflight approach.

The STS cost factor reflects the assumption that STS operations in the 1990 time frame will have reached a steady state efficiency which yields costs similar to the current user charge. The Orbit Transfer Vehicle cost factor approximates recent experience with IUS/Centaur class OTV's.

Costs are life cycle for the period 1985 - 2000, covering DDT&E, Production and Operations and Maintenance.

GROUND RULES AND ASSUMPTIONS

- ALL COSTS IN 1984 DOLLARS WITHOUT FEE
- 90% LEARNING CURVE WHERE APPROPRIATE
- SPACE STATION IS A NEW START IN 1985 (FY 1986)
- HABITABLE MODULES
  - FIRST MODULE TYPE IS PROTOTYPED
  - SUBSEQUENT MODULES INHERIT DDT&E
- PROTOFLIGHT APPROACH FOR ALL OTHER MODULES
- STS COST PER FLIGHT: $86M
- CONVENTIONAL ORBIT TRANSFER VEHICLE: $42M
- COSTS COVER 1985 - 2000

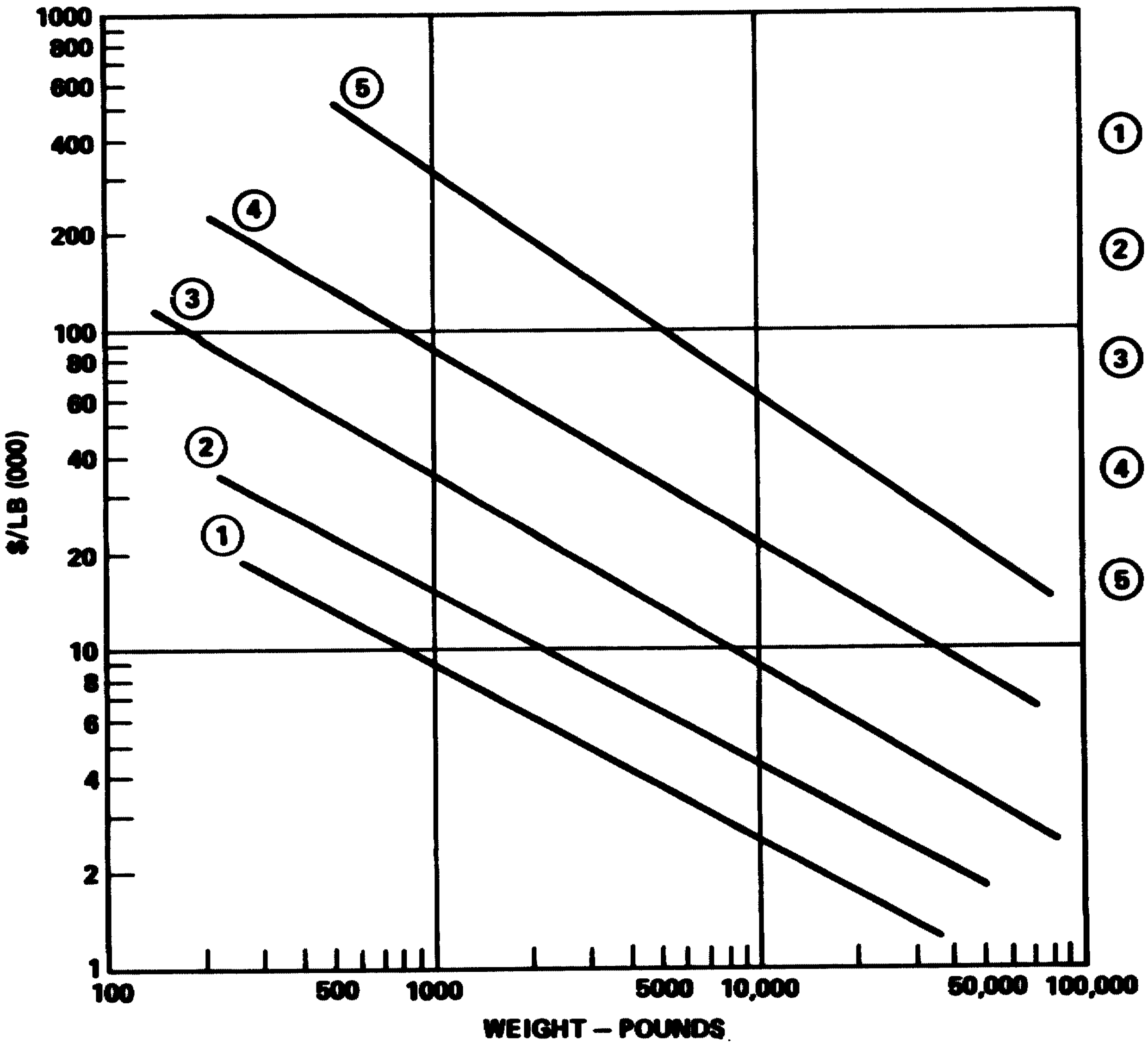
SPACE STATION ELEMENTS

DDT&E COST ESTIMATING RELATIONSHIPS

The cost estimating relationships (CER's) used for the hardware elements of the space station are based upon mathematical relationships between \$/lb and weight in pounds of the hardware. The form of the relationship is $\$/lb = a(wt)^b$ where a and b are constants determined by a regression derived from the cost data base. On a log-log scale, the relationship is represented by a straight line. Given its weight, Module costs are determined by multiplying the \$/lb by the weight. The CER's were developed at the module level as this would be the appropriate level for an architectural study. Subsystem build-up cost estimates were used only as necessary to support the derivation of the CER's. For example, the cost of a short habitability module was estimated using a subsystem build-up where the subsystem weight estimates were available. This estimated cost was then used as a data point to aid in deriving the habitability module CER.

All space station modules were categorized into 5 levels of complexity as shown on the graph with the habitability module representative of the highest complexity module and structures as representative of the lowest level of complexity. Protoflights were assumed for all modules except the habitable module (Manned Laboratory, habitability module and short habitability module) where a common prototype unit was assumed to be available for each of the habitable module prototype testing and evaluation. The protoflight assumption resulted in an estimated reduction of DDT&E CER by 30%. Thus, the protoflight savings is assigned to the development costs rather than making a special cost provision for the production or flight unit CER.

SPACE STATION ELEMENTS
DDT&E COST ESTIMATING RELATIONSHIPS
1984 DOLLARS



1. STRUCTURE
COMPLEXITY = 1
$\$/LB = 600\ (WT)^{-0.62}$

2. REBOOST MODULE
COMPLEXITY = 2
$\$/LB = 1200\ (WT)^{-0.62}$

3. S/C BUS
COMPLEXITY = 3
$\$/LB = 1700\ (WT)^{-0.62}$

4. SPACE PLATFORM
COMPLEXITY = 4
$\$/LB = 3531\ (WT)^{-0.62}$

5. HABITABILITY MODULE
COMPLEXITY = 5
$\$/LB = 48,546\ (WT)^{-0.727}$

TRW PROPRIETARY

SPACE STATION ELEMENTS

FIRST UNIT COST ESTIMATING RELATIONSHIPS

The methodology for deriving the First Unit CER's is the same as that used in developing the DDT&E CER's. There are five levels of complexity for each module and they correspond to the DDT&E definitions. A learning curve of 90% was used in production of more than one unit. If an interruption of at least one year occurs between production of units, then the costs will begin with the first unit costs again.

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SPACE STATION ELEMENTS FIRST UNIT COST ESTIMATING RELATIONSHIPS 1984 DOLLARS

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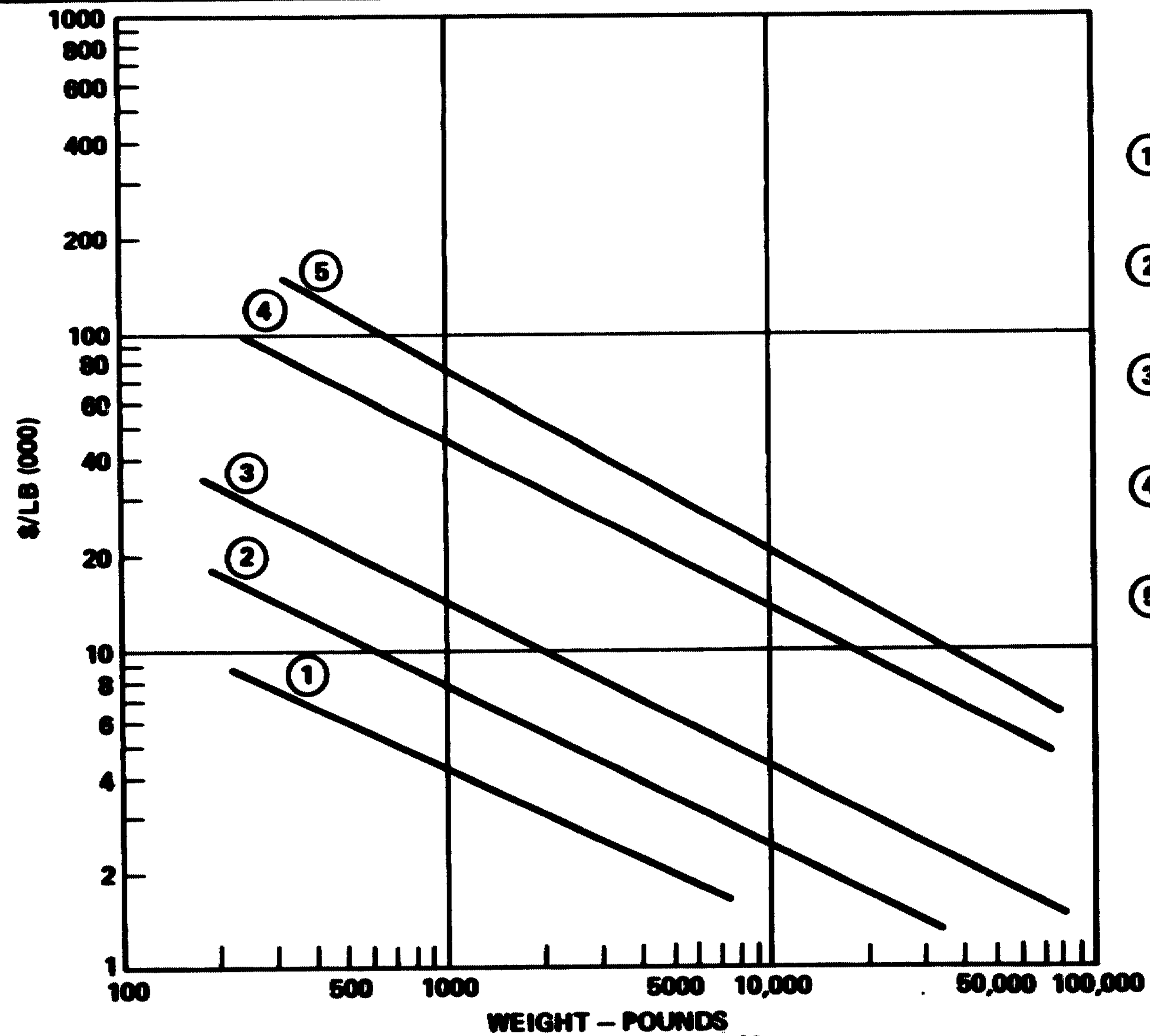

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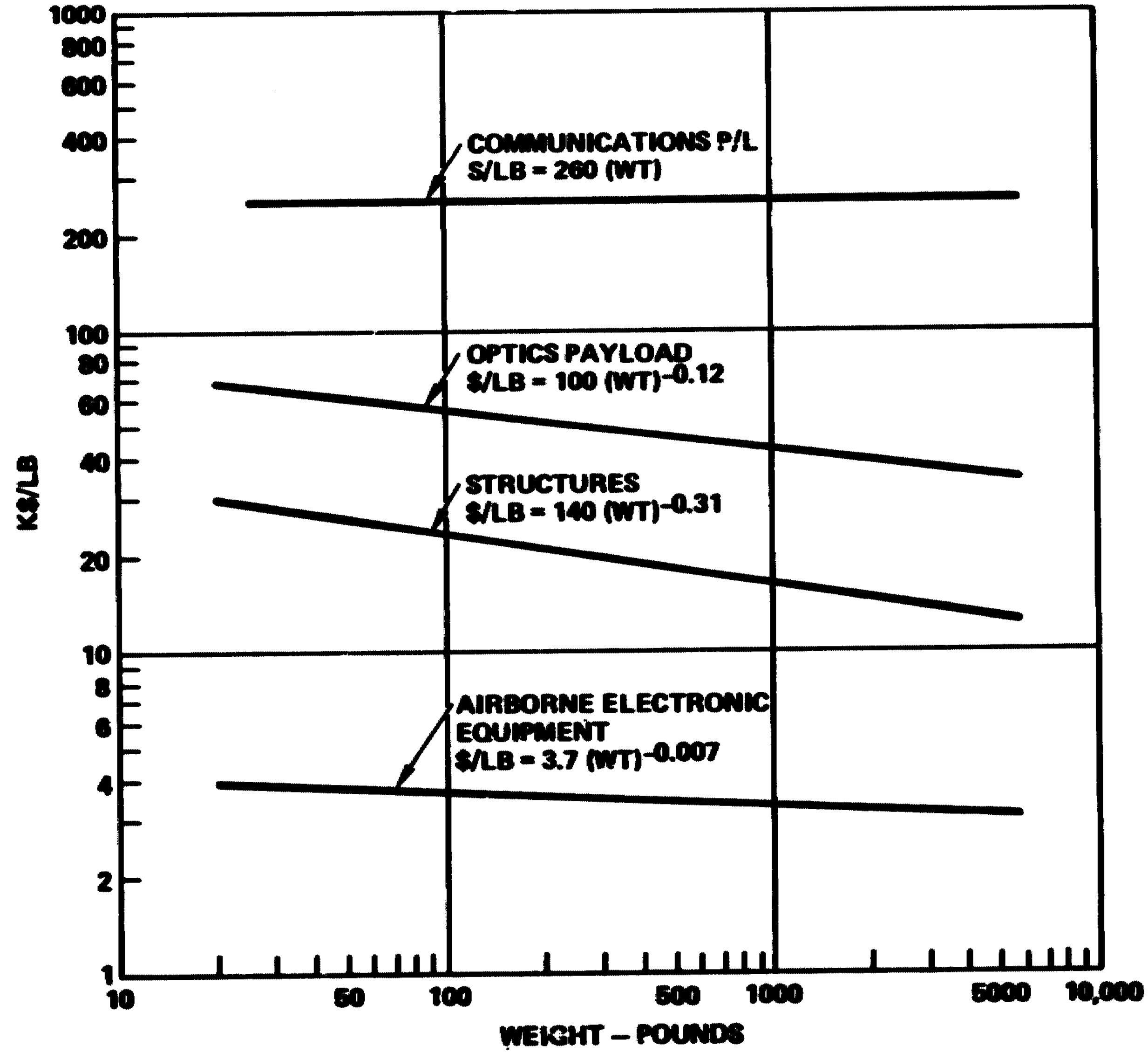
DDT&E MISSION P/L CER's

The system cost model includes the capability of determining mission cost for each mission given the weight of the mission payload or spacecraft. Although this study did not determine the cost of all missions in the Mission Model, some representative mission costs and costs for specific missions were estimated for the purpose of quantifying the benefits of the space station. To support such estimates, CER's were derived for four classes of payloads as shown in the chart. As was the case with the space station element CER's, the mission CER's for $/lb are power functions of weight and derived from TRW experience, information from consultants or the use of the RCA PRICE Model. In evaluating a specific mission, engineering judgement was used to determine whether the cost of a specific payload was represented by the CER's shown or somewhere in between. Thus, in some cases, the CER was factored as appropriate.

DDT&E MISSION P/L CERs
1984 THOUSANDS OF DOLLARS



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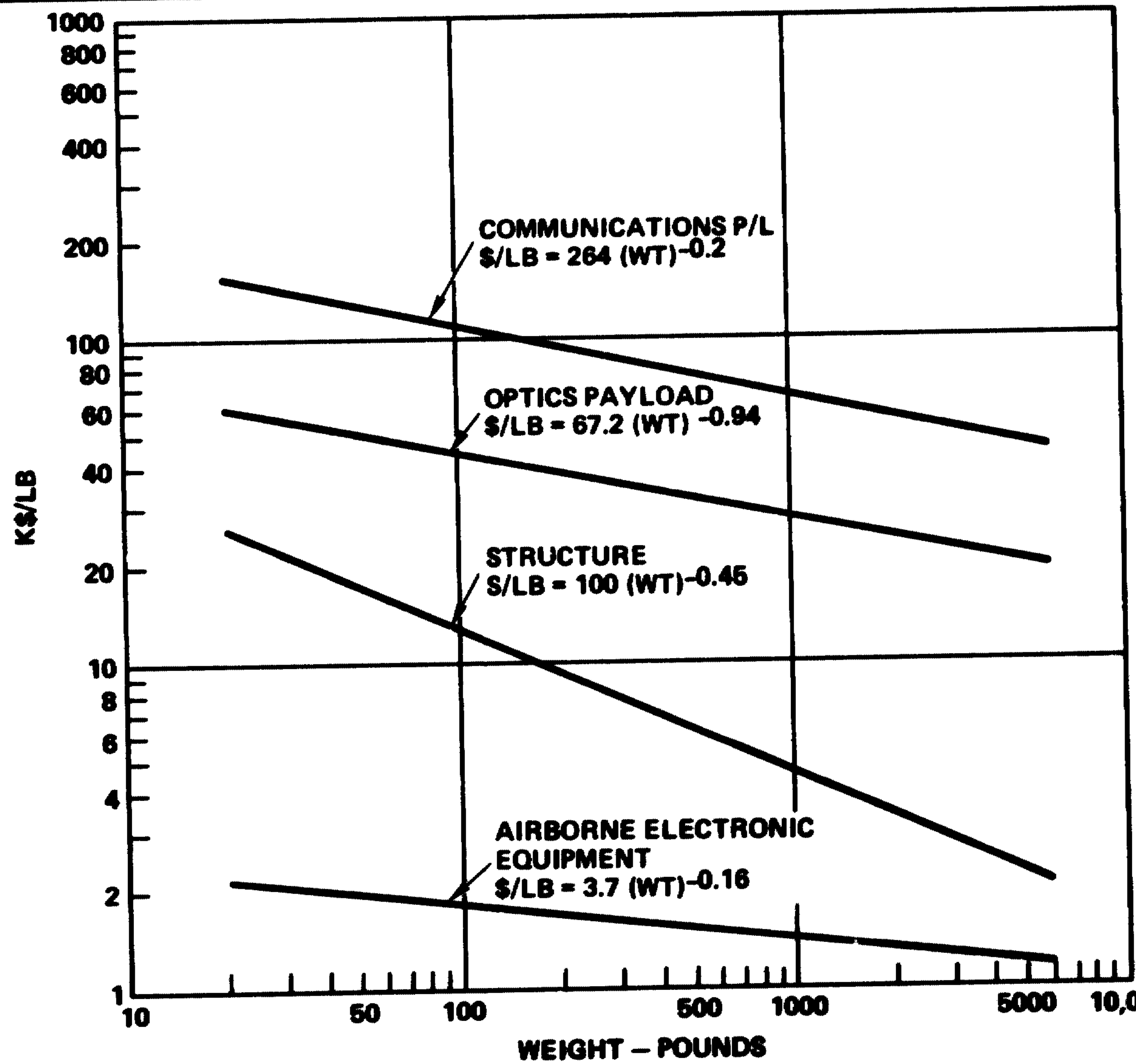
FIRST UNIT MISSION P/L CER's

The first unit mission payload CER's were developed from the same data sources as the DDT&E relationships. For multiple unit production, a learning curve of 90% was assumed.

FIRST UNIT MISSION P/L CERs
1984 THOUSANDS OF DOLLARS



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MAJOR MODULE COST ESTIMATES

The major cost elements in the cost analysis are shown in the accompanying table. The space station element costs were estimated using the CER's previously described. As expected, the significant cost items are the largest in weight and highest in complexity. The shared prototyping of the habitability module (HM), the Manned Laboratory Module (MLM) and the short habitability Module (SHM) is evident by the relatively low cost of the HM and SHM DDT&E compared to the MLM DDT&E. The full development cost was assigned to the MLM while the HM and SHM DDT&E costs were assumed to be 50% of their respective first unit costs. It was assumed that the MLM prototype could be modified to serve as prototypes for the HM and SHM.

The shuttle costs were assumed to be $86 million per flight. A modified orbiter is used in one of the specified scenarios, Scenario 5. The costs for this modification were based upon a subjective evaluation of the extent of the modifications. Estimates of OTV's were based upon analogy to a class of propulsive vehicles, while the cost estimates for the Teleoperating Maneuvering System were based upon estimates from Vought Corporation.

Development costs for the expendable OTV and the TMS were not considered as a cost attributable to the space station.

MAJOR MODULE COST ESTIMATES

	WEIGHT (POUNDS)	RELATIVE COMPLEXITY	COSTS MILLIONS OF 1984 DOLLARS DDT&E	FIRST UNIT
HABITABILITY MODULE	37,200	5	179	358
MANNED LAB MODULE	30,100	5	811	327
SHORT HAB MODULE	26,300	5	155	310
RESOURCE MODULE	27,000	4	281	236
LOGISTIC MODULE	13,900	4	219	172
JUNCTION MODULE	9,000	4	185	140
SHUTTLE	–	–	–	86
ORBITER MODS	–	–	100	200
EXPENDABLE OTV	–	–	–	42
AEROBRAKED REUSABLE OTV	–	–	700	50
TMS	–	–		25

OTHER COSTING FACTORS

The cost of three major space stations elements were estimated separately from the other cost models. These are system level management and integration (SMI), ground operations at the launch facilities and ground terminals. For all cases, the estimates were made using TRW experience. The SMI was estimated at eight percent of the system hardware costs while the ground operations and ground terminals were estimated using analogy to past programs. The ground terminals consist of three facilities - a space platform control center, a space station control center and a data handling facility.

OTHER COSTING FACTORS

SYSTEM LEVEL MANAGEMENT AND INTEGRATION

- ESTIMATED AT ROUGHLY 8% OF SPACE STATION HARDWARE COSTS

GROUND OPERATIONS AT LAUNCH FACILITIES

- FACILITIES, EQUIPMENT AND TEST REQUIREMENTS ESTIMATED BY ANALOGY
- LABOR HOURS ESTIMATED BY TASK

GROUND TERMINALS

- 3 COMPONENTS
  - SPACE PLATFORM CONTROL CENTER: $0.3 BILLION ACQUISITION
  - SPACE STATION CONTROL CENTER: $0.2 BILLION ACQUISITION
  - DATA HANDLING FACILITY: $0.2 BILLION ACQUISITION
- ESTIMATES BY ANALOGY TO CONSOLIDATED SPACE OPERATIONS CENTER (CSOC)

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Cost Summary By Scenario

SPACE STATION ARCHITECTURE SCENARIOS

Six different candidate scenarios were examined. All had free-flying spacecraft, small unmanned platforms, TMS and OTV's in common.

Scenario 0 is the baseline. This assumes neither a space station (SS) or a space platform (SP). It is what would/could be done without those elements. Scenario 1 adds space platforms. Scenario 2 has space stations, but no space platforms. Scenario 3 has an SS at LEO and one large SP at PEO.

Scenario 4 has SS's at LEO and PEO and an SP at LEO. Scenario 5 is like Scenario 4 except that an extended-stay orbiter is used as part of the initial SS.

Space Station Architecture Scenarios

SCENARIO	SPACE PLATFORM		SPACE STATION	
	LEO*	PEO	LEO	PEO
0				
1	X	X		
2			X	X
3		X	X	
4	X		X	X
5**	X		X	X

*LEO – LOW INCLINATION (28.5°) LOW EARTH ORBIT
PEO – POLAR (97°) LOW EARTH ORBIT

**USES STS AS PART OF INITIAL SS

ALL SCENARIOS INCLUDE FREE FLIERS, SMALL UNMANNED PLATFORMS, TMS, OTV'S

LIFE CYCLE COST COMPARISON OF SCENARIO (1985 - 2000)

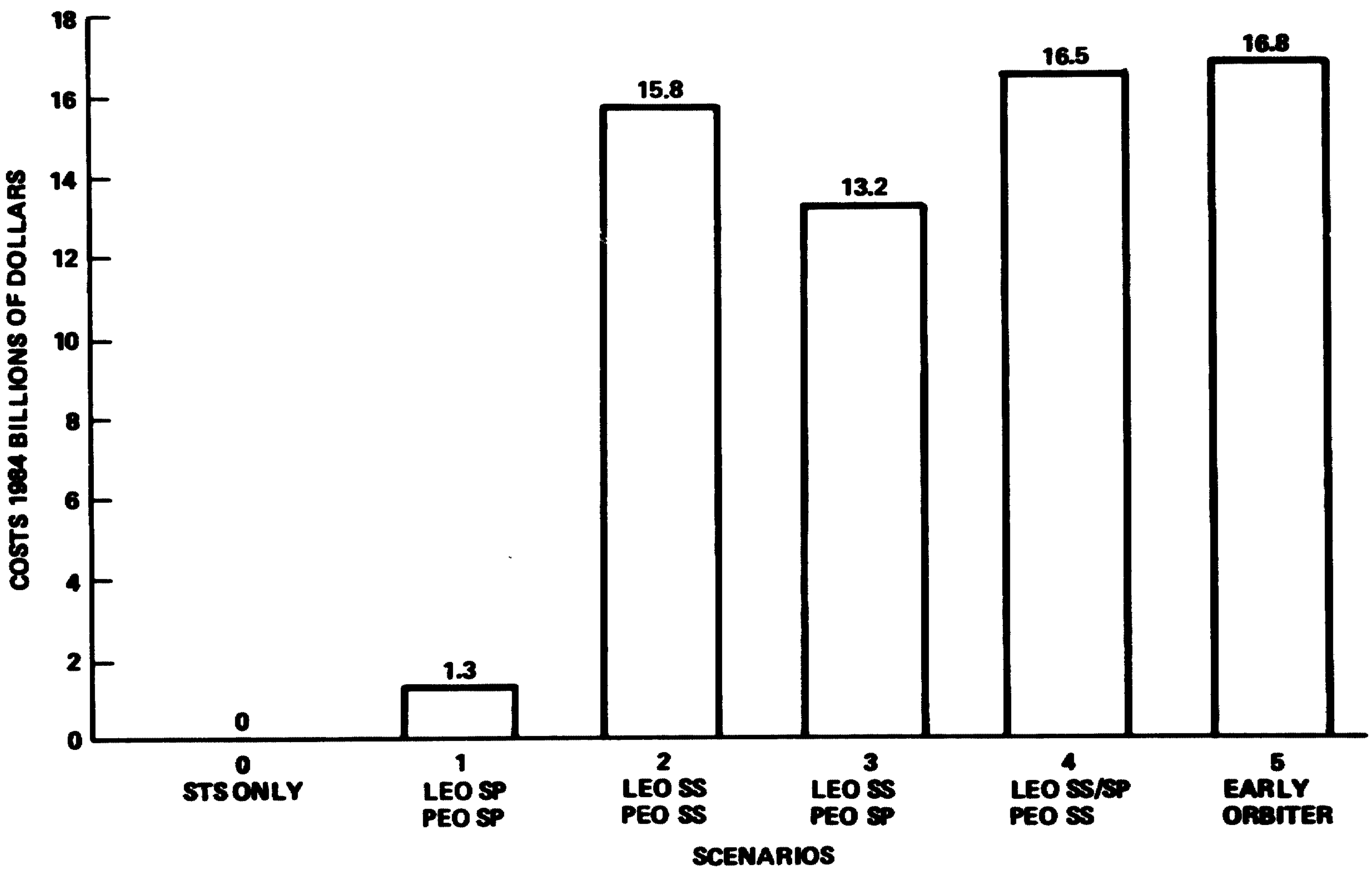
This chart compares the total Life Cycle cost of the various scenarios. Scenario 0 (STS only) is included as a frame of reference. Scenario costs shown here are for system elements over and above those contained in Scenario 0.

Scenario 1, the Space Platform case, is clearly the least expensive. Man is not a part of this architecture, thus man-rated development and frequent O&M STS flights are not required. However, this scenario does not deliver the benefits of the manned scenarios, as will be demonstrated.

Scenario 2 shows the cost for manned space stations in LEO and PEO. Scenario 3 eliminates the PEO Space Station and adds space platforms in PEO. Scenario 4 equates to Scenario 2 with the addition of a LEO Space Platform. Scenario 5 adds to this the establishment of an early manned capability through the use of the orbiter.

Of the manned scenarios, Scenario 3 is the least expensive. But this was obtained by eliminating the PEO Space Station. The impact on benefits is addressed in the charts that follow.

LIFE CYCLE COST COMPARISON OF SCENARIOS (1985 - 2000)



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SPACE STATION COSTS BY PHASE

The fully deployed space station takes place in three phases with the major capabilities being deployed in 1990, 1995 and 2000. This table presents the estimated life cycle costs for each scenario for the phases encompassing the years 1985-1990, 1991-1995 and 1995-2000. The initial capability in 1990 for each LEO space station will have a crew of 5 and 30 kW of power. This will be increased to a crew of 8 in 1995 with 60 kW of power and finally by the year 2000, there will be a crew of 10 with 60 kW of power. For the polar orbit (PEO), the space station will be deployed initially in 1995. The crew size will remain at three and the power capability will remain at 30 kW for the 1995-2000 period.

For those scenarios with space stations, the phase costs vary from $3.2 billion for the third phase of Scenario 3 where only a LEO station exists to $6.0 billion for the first phase of Scenario 5. The important first phase costs vary from $5.4 billion to $6.0 billion. This small variation in costs for the first phase is accounted for by slight variations in the phasing of development and production for each scenario and the greater costs in Scenario 5 for a modified orbiter. The peak year costs vary from $1.3 billion to $1.5 billion reflecting the variation of total costs for each scenario.

SPACE STATION COSTS
BY PHASE
BILLIONS OF 1984 DOLLARS

SCENARIO	PHASE (YEARS) 1985-90	1990-95	1996-2000	TOTAL COSTS	PEAK YEAR COSTS
1	0.8	0.4	0.1	1.3	0.1
2	5.5	5.7	4.6	15.8	1.4
3	5.4	4.6	3.2	13.2	1.3
4	5.7	5.9	4.9	16.5	1.5
5	6.0	5.9	4.9	16.8	1.5

SCENARIO COST COMPARISONS

This chart provides a cost comparison of the six scenarios by WBS element for both the space station and the missions excluding the payload and spacecraft. The cost figures indicate that scenario 3's lower costs compared to the other three scenarios having space stations is due to the space segment costs and STS costs. This is expected as this scenario does not have a space station in PEO. The STS costs are a prominent portion of each of the scenarios with a space station. The STS costs vary from 32% to 37% of the total space station costs.

The significant reduction in mission costs due to the presence of the space station is evident from the chart. The cost reductions vary from $2 billion for Scenario 1 to $14.4 billion for Scenarios 4 and 5. The STS costs represent a substantial portion of the mission costs shown. These mission costs exclude the mission payload and spacecraft costs. In this cost analysis, our focus is upon potential cost savings due to the space station and thus the mission costs have dealt only with the estimates of potential cost reductions in mission payload and spacecraft costs rather than attempting to determine the cost of the entire mission model. A more comprehensive discussion of these cost saving benefits is presented in later charts.

SCENARIO COST COMPARISONS
BILLIONS OF 1984 DOLLARS

TRW

WBS ELEMENT	SCENARIO					
	0	1	2	3	4	5
SPACE STATION (SS)						
SPACE SEGMENT	–	0.8	8.0	6.8	8.3	8.6
GROUND SEGMENT	–	0.3	1.3	1.6	1.6	1.6
SYSTEM LEVEL MANAGEMENT AND INTEGRATION	–	–	0.6	0.6	0.6	0.6
STS	–	0.2	5.9	4.2	6.0	6.0
SS COSTS	–	1.3	15.8	13.2	16.5	16.8
MISSIONS						
UNMANNED PLATFORMS	2.6	1.0	1.6	1.6	1.0	1.0
STS	29.0	28.6	18.2	18.5	18.2	18.2
OTV/AKM	5.5	5.5	3.5	3.5	3.5	3.5
TOTAL EXCLUDING PAYLOADS AND SPACECRAFT	37.1	36.1	23.3	23.6	22.7	22.7

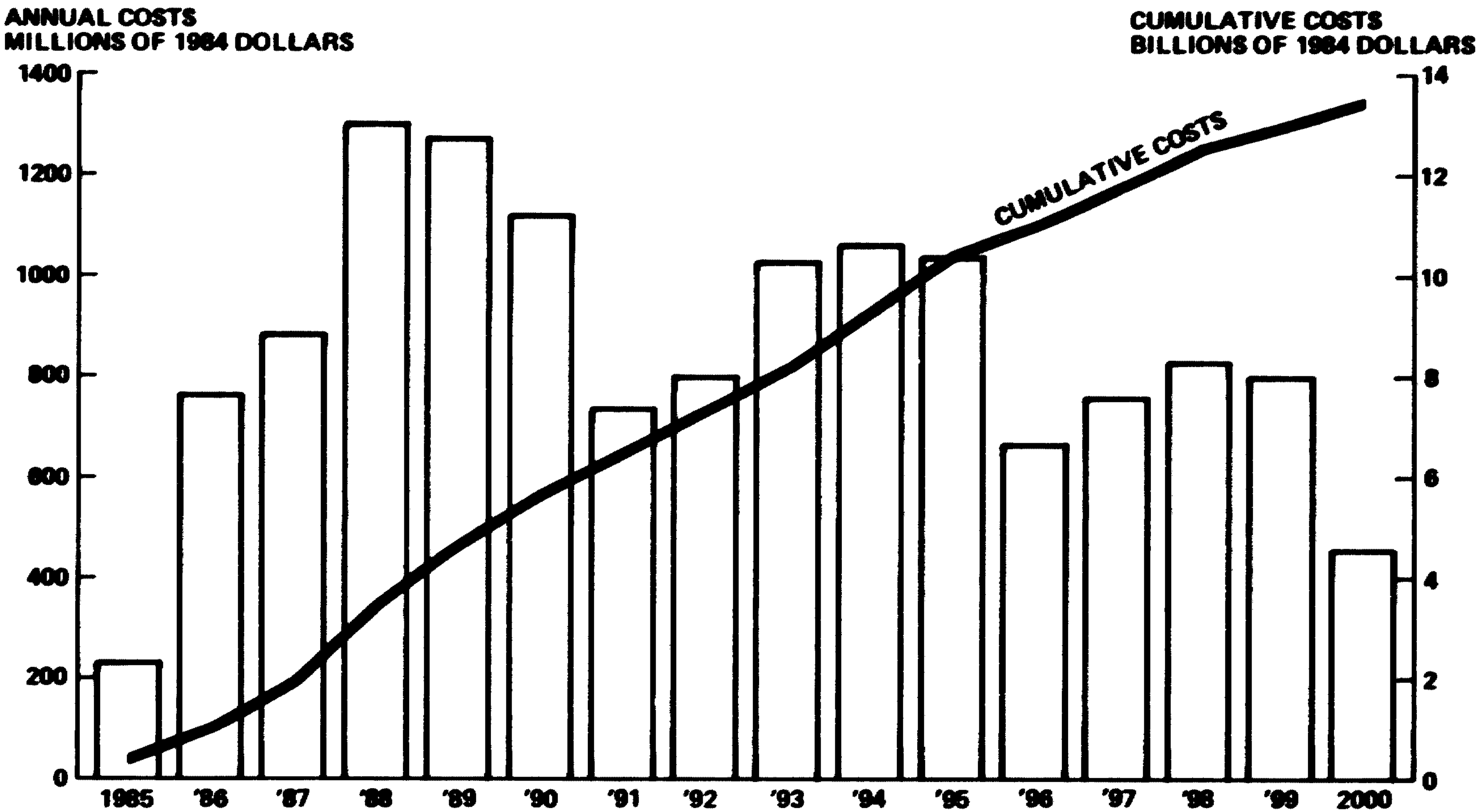
SPACE STATION COSTS - ANNUAL AND CUMULATIVE TOTALS

This graph presents funding requirements for the Scenario 3 Space Station Program. The left scale refers to the annual data (the bars) while the right scale refers to the cumulative data (the line).

The peak funding occurs in 1988 and is $1.3 billion. The three phases of Scenario 3 require funding as follows:

o	Initial	1985 - 1990	$5.4B
o	Interim	1991 - 1995	4.6B
o	Growth	1996 - 2000	3.2B
		Total	$13.2B

SPACE STATION COSTS
ANNUAL AND CUMULATIVE TOTALS
SCENARIO 3



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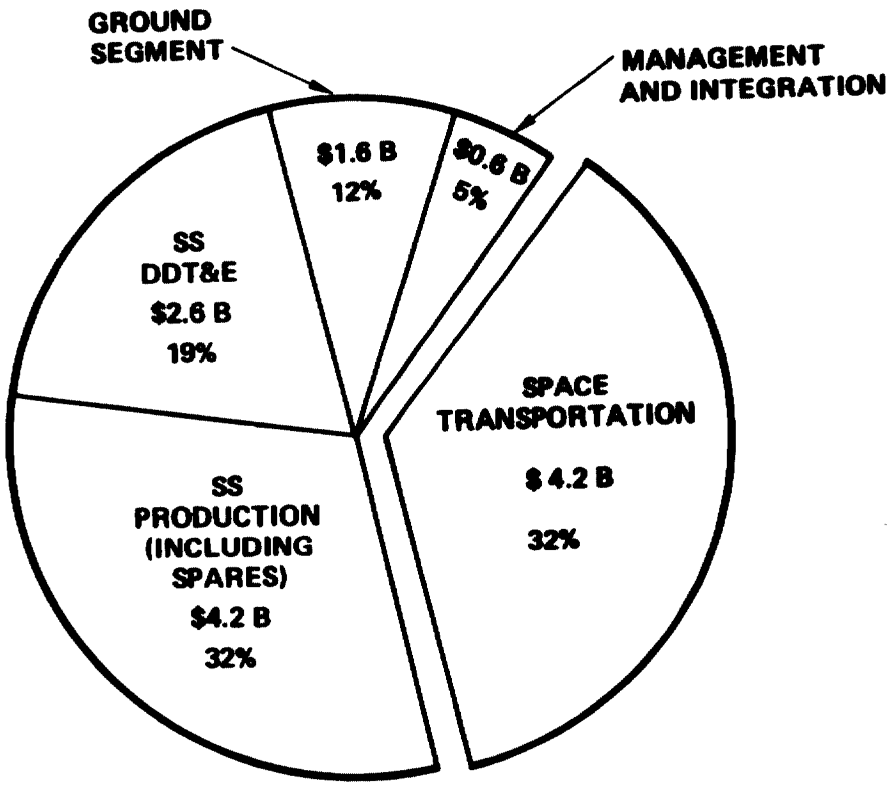
DISTRIBUTION OF LIFE CYCLE COSTS FOR SCENARIO 3

This chart shows the distribution of the $13.2 billion space station system cost of Scenario 3 into the major WBS elements. Half the cost goes to acquire and maintain the Space Segment, one-third provides for space transportation while the remainder provides for the ground segment and management and integration. The space transportation costs match the space system production costs.

DISTRIBUTION OF LIFE CYCLE COSTS FOR SCENARIO 3



SPACE TRANSPORTATION COSTS ARE A MAJOR FACTOR

DISTRIBUTION OF LIFE CYCLE COSTS
FOR SCENARIO 3
BY ACTIVITY (1985 - 2000)

This chart indicates the distribution of costs among the four major activities - development, production, deployment and operations and maintenance (O&M) for the space station in the period from 1985 to 2000. The largest (36% of the total) segment of costs is operations and maintenance with most of this ($2.9 billion) representing STS transportation. The production costs nearly match the O&M costs at $4.6 billion.

The development of the space station is estimated to cost $2.6 billion or 20% of the life cycle costs. The deployment costs represent STS costs to place the space station modules into its desired orbit. Deployment contributes 9% to the total costs.

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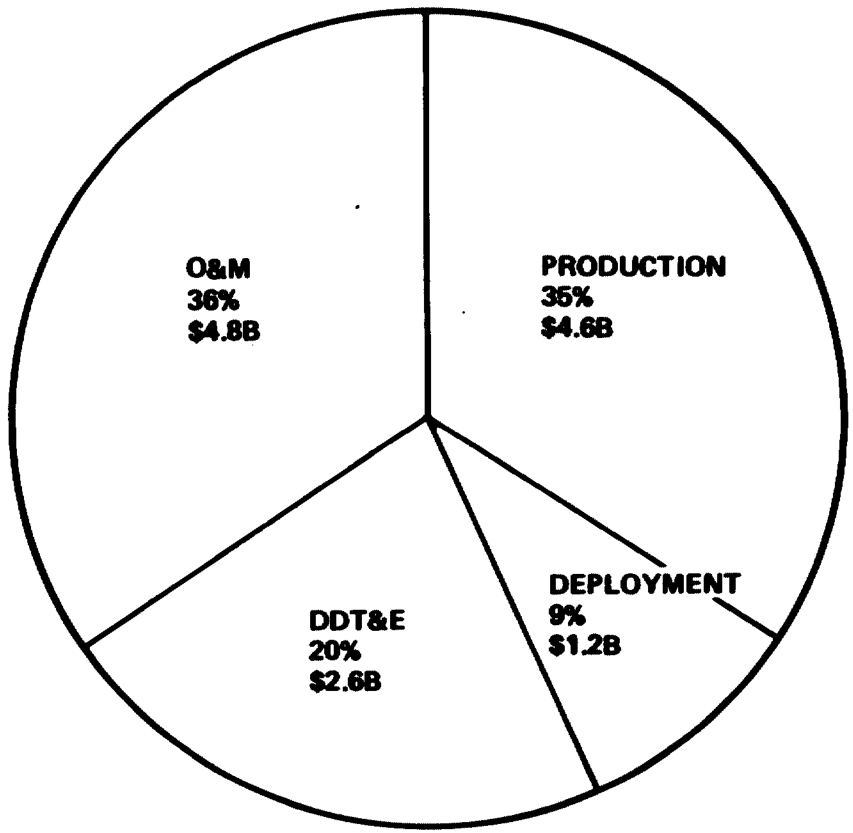
DISTRIBUTION OF LIFE CYCLE COSTS FOR SCENARIO 3 BY ACTIVITY (1985-2000)



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Cost Benefit Assessments

SPACE STATION BENEFITS

There are many benefits to be obtained from establishing a manned space station. This chart summarizes them. The benefits are divided into three separate categories: Social, Performance and Economic. For the purpose of evaluating the various scenarios the Economic benefits were quantified as demonstrated in the charts that follow.

The Social and Performance benefits, while not quantified, were considered in the scenario selection. Note that they are obtained with all manned space station scenarios, but not with Scenario 1 which consists of only Space Platforms.

SPACE STATION BENEFITS

SOCIAL

- NATIONAL PRESTIGE
- LEADERSHIP IN SPACE
- INTERNATIONAL COOPERATION
- NEW HUMAN OPPORTUNITIES
- FOSTER COMMERCIAL OPERATIONS
- MOTIVATE TECHNICAL EDUCATION

PERFORMANCE

- BETTER MAN-IN-SPACE USE
- ENHANCE NATIONAL SECURITY
- BASECAMP: STEPPING STONE
- MAINTAIN/ACCELERATE SCIENTIFIC MOMENTUM
- HIGH TECHNOLOGY FALLOUT

ECONOMIC

- ORBIT TRANSFER
- STS LOAD FACTOR
- MANNED LABORATORY
- SATELLITE SERVICING
- ON-ORBIT ASSEMBLY
- REDUCED UNMANNED PLATFORMS

QUANTIFIABLE BENEFITS DEFINITION

For the purpose of estimating, analyzing and evaluating benefits, the quantifiable benefits for this study are defined as the Mission Cost savings attributed to the introduction of a space station and/or space platforms. Scenario 0 (zero) has been defined as that scenario in which only the STS is available to support the Mission Model developed in Task 1. Given that the costs are determined for Scenario 0, benefits would accrue to the introduction of a space system to support the missions if a reduction in scenario costs occurred. Thus, our benefits represent cost savings. The cost savings may be due to reduced space transportation (STS or OTV's), reduced mission payload or spacecraft costs or the reduced cost in payload carriers (unmanned platforms).

QUANTIFIABLE BENEFITS DEFINITION

QUANTIFIABLE BENEFITS = MISSION COST SAVINGS ATTRIBUTED TO SPACE STATION

(COST REDUCTION TO SCENARIO 0)

COST BENEFIT "ALGEBRA"

As a method of further defining our interpretation of benefits as cost savings, the accompanying chart illustrates the algebra of cost comparisons between a scenario involving a space station and Scenario 0. In Scenario 0, the three cost elements are the mission payload and spacecraft costs, the cost of payload carriers or unmanned platforms and transportation costs. Scenario 4 has these same elements but in addition, Scenario 4 has the costs of the space station and space platforms (SS/SP). Net benefits are defined as the cost difference between Scenario 4 and Scenario 0 when such a difference is positive. Algebraically this is shown by subtracting the elements of Scenario 4 costs from Scenario 0 costs. By rearranging terms, the components of benefits can be derived where the mission payload/spacecraft (PL/SC) benefits are defined as the difference in the PL/SC costs of the two scenarios.

Similar definitions are derived for the unmanned platforms (UP) and the transportation benefits. Thus net benefits can be defined as the difference between the total benefits and the SS/SP costs. This definition is important since the various categories of space station benefits can be evaluated by its amount of savings in these three generic areas of cost reduction.

COST BENEFIT "ALGEBRA"

SCENARIO 0 COSTS

① MISSION PL + SC COSTS

② UNMANNED PLATF COSTS

③ TRANSPORTATION (STS, OTV)

SCENARIO X COSTS

①′ MISSION PL + SC COSTS

②′ UNMANNED PLATF COSTS

③′ TRANSPORTATION (STS, OTV)

④′ SS + SP COSTS

SCENARIO 0 COSTS − SCENARIO X COSTS = NET BENEFITS

$$① + ② + ③ - ①' - ②' - ③' - ④' = \text{NET BENEFITS}$$

$$\underbrace{\underbrace{① - ①'}_{\text{PL/SC BENEFITS}} + \underbrace{② - ②'}_{\text{UP BENEFITS}} + \underbrace{③ - ③'}_{\text{TRANSP BENEFITS}}}_{\text{TOTAL BENEFITS}} - \underbrace{④'}_{\text{SS + SP COSTS}} = \text{NET BENEFITS}$$

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SPACE STATION FINANCIAL BENEFIT QUANTIFICATION

As indicated in the prior charts, there are four basic cost elements in implementing the Mission Model: Space Transportation, Payloads, Spacecraft and Unmanned Platforms. The Various Economic benefit categories were identified which impact these cost elements.

ORBIT TRANSFER. Space Station enables the establishment of an Aerobraked Reusable Orbit Transfer Vehicle. This vehicle reduces the cost of orbit transfer due to reusability and non-propulsive braking, resulting in a Mission Segment cost savings and a Space Station benefit.

STS LOAD FACTOR. Space Station provides the opportunity to warehouse space hardware so that STS flights can be more fully loaded. This increased STS load factor reduces Mission Segment STS flights and transportation costs.

MANNED LABORATORY. Mission Costs for the Manned Laboratory are saved in that it is a permanent part of the Space Station and the cost of transporting it up and down repeatedly is avoided.

SATELLITE SERVICING. The Economic benefit of the Space Station comes from the difference in cost between servicing satellites from the Space Station or from the STS.

ON-ORBIT ASSEMBLY. The availability of a manned Space Station will enable satellite assembly on orbit. This will benefit outsized missions as well as allow increased efficiency in satellite assembly and test, thereby saving mission costs.

REDUCED UNMANNED PLATFORMS. For scenarios that include Space Platforms fewer unmanned Platforms are required, thus a cost savings over Scenario 0.

SPACE STATION FINANCIAL BENEFIT QUANTIFICATION

SPACE STATION BENEFITS	MISSION SEGMENT COST ELEMENTS			
	TRANSPORTATION	PAYLOADS	SPACECRAFT	UNMANNED PLATFORMS
ORBIT TRANSFER	X			
STS LOAD FACTOR	X			
MANNED LABORATORY	X			
SATELLITE SERVICING	X	X	X	X
ON-ORBIT ASSEMBLY	X	X	X	X
REDUCED UNMANNED PLATFORMS	X			X

- A SPACE STATION FINANCIAL BENEFIT IS A MISSION SEGMENT COST SAVINGS OVER STS ONLY SCENARIO

SPACE STATION "BALANCE SHEET"

Twelve specific and significant areas of space station (SS) benefits were identified in this study, of which six generic areas were described on the prior chart. For each of these SS benefit areas, the cost savings due to the availability of the space station and space platform were quantified relative to the reduced costs in mission hardware costs, reduced need for unmanned platforms or reduced transportation costs. Given that net benefit is defined as the difference between total benefits and costs, a "balance sheet" can be constructed to itemize the components of benefits and costs. For purposes of illustration, Scenario 3 is chosen to present the balance sheet items. As will be seen later, Scenario 3 is also the most favorable scenario based upon our cost benefit assessment.

A review of the benefits indicates that four benefit areas provide 75% of the total benefits with improved STS load factor providing the largest amount - over $5 billion for the period 1985 - 2000. This is followed by Geosynchronous Satellite Servicing, Manned Laboratory accomodations and Aerobraked Reusable Orbit Transfer Vehicle efficiency ranging from $2.5 billion to $3.3 billion in benefits. The space station/space platform system costs total $13.2 billion compared to the $18.4 billion in benefits resulting in $5.2 billion in net benefits.

SPACE STATION "BALANCE SHEET"
BILLIONS OF 1984 DOLLARS
SCENARIO 3

SS BENEFITS		SS COSTS[1]	
IMPROVED STS LOAD FACTOR	$ 5.1 B	SPACE STATION/SPACE PLATFORM	$6.8 B
GEO SAT SERVICING	3.3	SPACE TRANSPORTATION	4.2
MANNED LAB ACCOM	2.9	GROUND ACTIVITIES	1.6
AROTV EFFICIENCY	2.5	SYS. ENG. & INTEG.	0.6
UNMANNED PLATFORM	1.3		$13.2
ON-ORBIT AI&T	0.7		
LARGE INSTR ASSEMBLY	0.7		
LEO SAT SERVICING	0.5		
REMOTE SENSING ACCOM	0.0		
MPS ACCOM	0.3	NET BENEFITS	5.2
MSSR ACCOM	0.3		
COMSAT TRANSHIPMENT	0.8		
TOTAL BENEFITS	$18.4	TOTAL COSTS AND NET BENEFITS	$18.4

[1]COSTS INCLUDED DDT&E, PROD, DEPLOYMENT AND O&M FOR SCENARIO 3.

TOTAL BENEFIT DISTRIBUTION

SCENARIO 3

The distribution of total benefits among science and application missions, commercial missions and DoD missions are presented in the accompanying chart for each of the areas of benefits. This distribution was determined by identifying which mission would receive a specific type of benefit and estimating the amount. The commerical missions would receive over one-half of the identified quantifiable benefits with science and application missions gaining 29% and Dod gaining 20%. The largest benefit contributor to the science and application missions and commercial missions is improved STS load factor while geosynchronous satellite servicing yields the largest potential for cost savings for the DoD missions.

TOTAL BENEFIT DISTRIBUTION
BILLIONS OF 1984 DOLLARS
SCENARIO 3

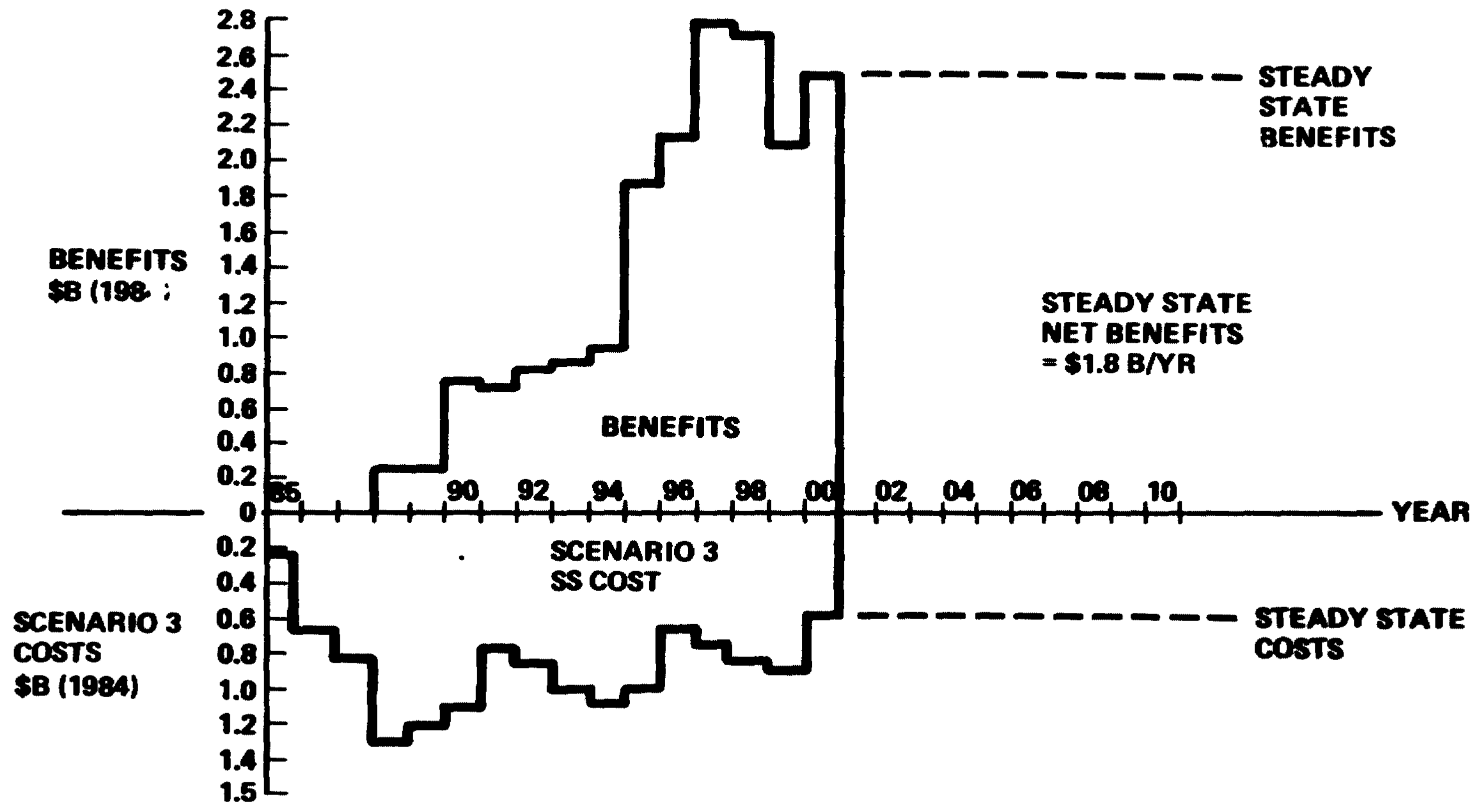
BENEFITS	SCIENCE AND APPLICATIONS	COMMERCIAL	DoD
AROTV	$0.0 B	$1.7 B	$0.8 B
GEO SAT SERV	0.0	1.5	1.8
MANNED LAB	1.0	1.9	0.0
STS LOAD FACTOR	1.9	2.3	0.9
LARGE INST ASSY	0.7	0.0	0.0
MSSR	0.3	0.0	0.0
LEO SAT SERV	0.5	0.0	0.0
MAT'L PROC	0.0	0.3	0.0
REMOTE SENSING	0.0	0.0	0.0
ON–ORBIT AI&T	0.2	0.3	0.2
COMSAT TRANSHIPMENT	0.0	0.8	0.0
UNMAN PLATF	0.7	0.6	0.0
	$5.3 B	$9.4 B	$3.7 B
	29%	51%	20%

TIME DISTRIBUTION OF BENEFITS AND COSTS

This chart lays out the distribution of costs and benefits for Scenario 3. Benefits begin to accrue in advance of the Space Station deployment as satellite programs are configured to take advantage of Space Station attributes. The benefits continue to rise through 1995 where the introduction of the AROTV provides a significant step increase in benefit production for satellite deployment and geosynchronous satellite servicing. Also, in system capability established by the year 2000 provides a steady state benefit as shown.

The cost stream reflects three peaks consistent with the initial, interim and growth deployments of the Space Station. This leads to a steady state cost which reflects the O&M cost of the station. Comparison of the steady state benefit and cost in the years beyond 2000 yield the most significant net benefits, since in the prior years substantial costs were incurred due to the building of the space station to its full capabilities.

TIME DISTRIBUTION OF BENEFITS AND COSTS (SCENARIO 3)



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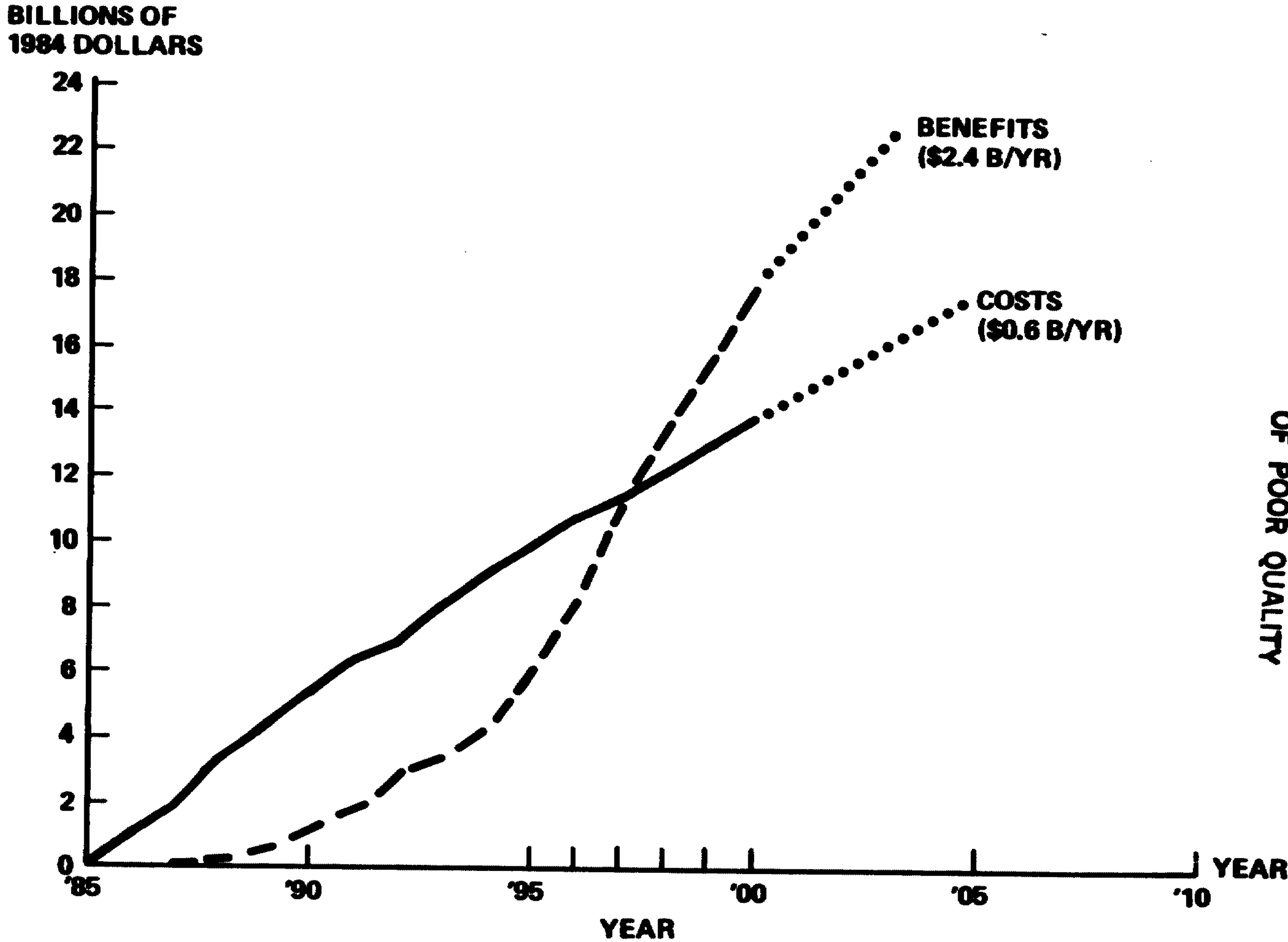
CUMULATIVE BENEFITS AND COSTS

This chart tracks the cumulative benefits and costs of Scenario 3. The crossover occurs in 1997 and by the year 2000 benefits significantly exceed costs. Steady state benefits of Scenario 3 can be seen as the difference in slopes of the dotted portions of cumulative cost and benefit graphs beyond the year 2000. The cumulative benefit and cost curves are diverging at the rate of $1.8 billion per year.

CUMULATIVE BENEFITS AND COSTS

SCENARIO 3



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SPACE STATION SCENARIOS ECONOMIC BENEFITS COMPARISON SUMMARY

This chart compares the total benefits of the 5 scenarios. Benefits differ depending on the missions and efficiencies that can be obtained from the particular configuration of the scenario.

Scenario 1 lacks man as part of the architecture and thus loses most of the economic benefits due the other scenarios. AROTV and STS Load Factor savings are not realized with a space platform-only configuration.

Scenario 3 delivers fewer benefits due to the absence of a Manned Space Station in PEO. This reduces the satellite servicing benefit accruing to the scenario.

Scenario 2 loses benefits due to the absence of a Space Platform, requiring more unmanned platforms to be acquired.

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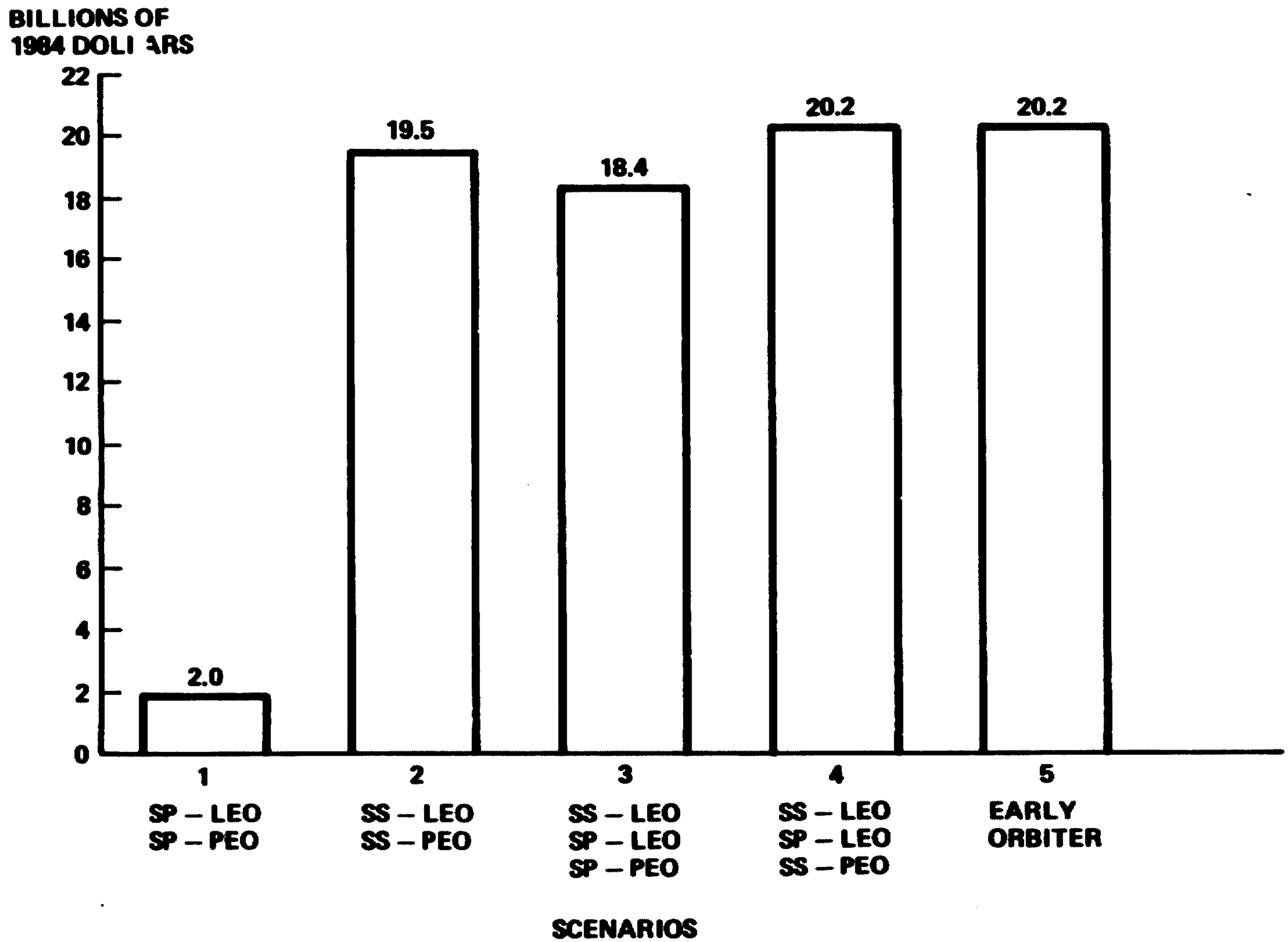
SPACE STATION SCENARIO ECONOMIC BENEFITS COMPARISON SUMMARY



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BENEFITS AND COSTS BY SCENARIO

This alternative chart also compares the costs and benefits of the various scenarios in order to develop a ranking. The most significant measures available are Net Benefits (Total Benefits less Total Costs) and Benefit-Cost Ratio (Total Benefits divided by Total Costs).

Scenario 1 ranks last by far in net benefits but first in benefit-cost ratio. This reflects a small but relatively efficient investment. It does not, however, generate the non-quantifiable benefits of man in space.

Scenarios 2 through 5 all share equally in the non-quantified benefits. Of these four, Scenario 3 is the clear leader in Net Benefits and the Benefits-Cost Ratio. Comparing Scenario 3 and 4 it is clear that the PEO Space Station costs more than the benefits it adds.

Other measures of comparison would be total benefits and total costs. Scenario 4 and 5 yield the most total benefits as both of these scenarios have the space station capabilities in both LEO and PEO and a space station in LEO. Scenario 1 would be the least costly alternative as only space platforms are used.

BENEFITS AND COSTS BY SCENARIO
BILLIONS OF 1984 DOLLARS
(1985 - 2000)

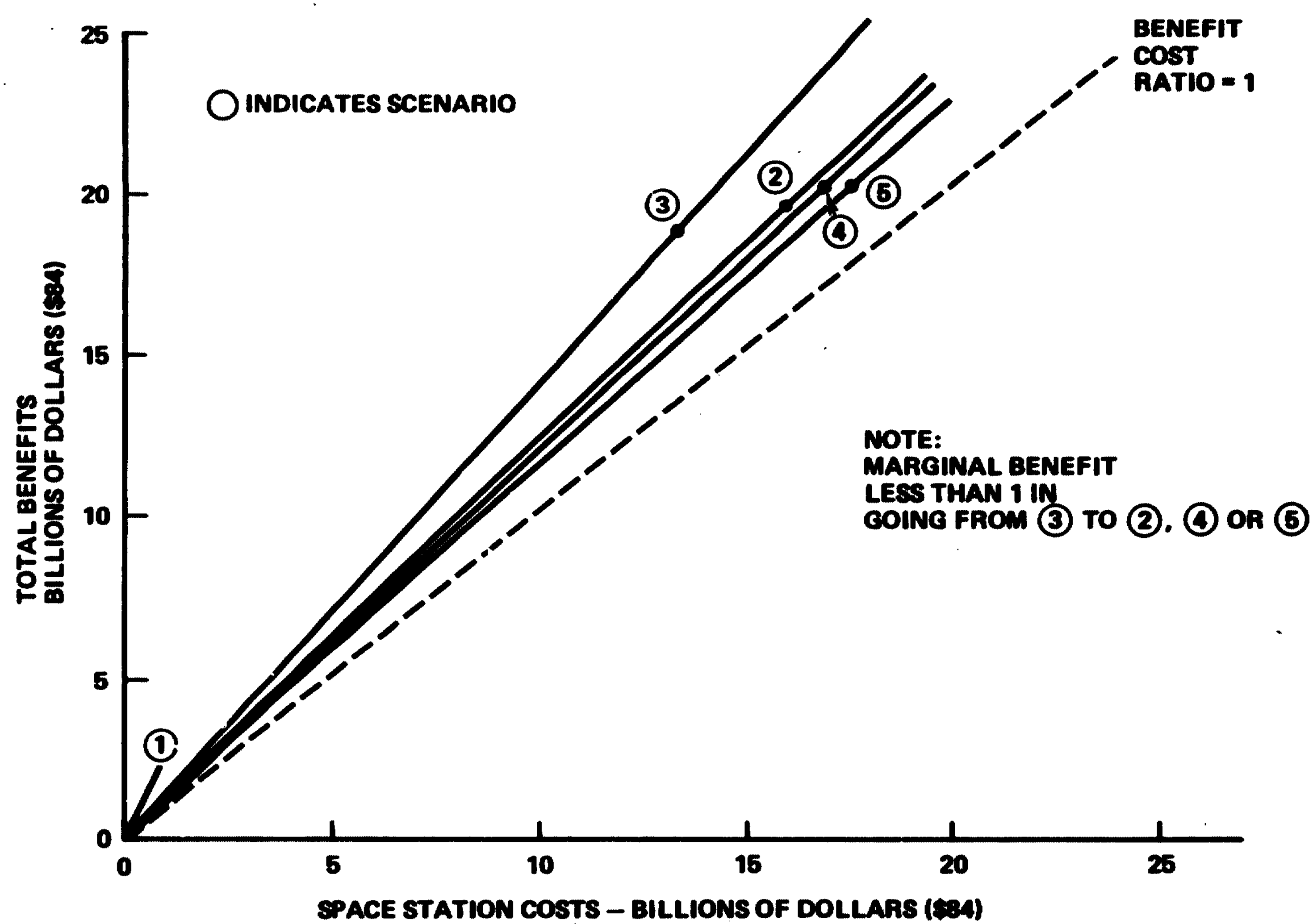
	SCENARIOS				
BENEFITS	**1**	**2**	**3**	**4**	**5**
STS LOADING FACTOR	–	5.4	5.1	5.3	5.3
GEO SAT SERV	–	3.3	3.3	3.3	3.3
MANNED LAB	–	2.9	2.9	2.9	2.9
AROTV	–	2.5	2.5	2.5	2.5
UP	2.0	1.3	1.3	2.0	2.0
ON-ORBIT AI&T	–	0.9	0.7	1.0	1.0
LARGE INST ASSY	–	0.7	0.7	0.7	0.7
LEO SAT SERV	–	0.5	0.5	0.5	0.5
REMOTE SENSING	–	0.6	–	0.6	0.6
MPS ACCOM	–	0.3	0.3	0.3	0.3
MSSR ACCOM	–	0.3	0.3	0.3	0.3
COMSAT TRANSHIPMENT	–	0.8	0.8	0.8	0.8
	2.0	19.5	18.4	20.2	20.2
SPACE STATION COSTS	1.3	15.8	13.2	16.5	16.8
NET BENEFITS	0.7	3.7	5.2	3.7	3.4
BENEFIT – COST RATIO	1.5	1.2	1.4	1.2	1.2

SPACE STATION COST BENEFITS

YEARS 1985 - 2000

This graphic depiction of the space station costs and benefits permits an alternative view of the conclusions drawn from the prior tables. The graph shows the total benefits and space station costs for each scenario. The slope of the line drawn to any scenario benefit-cost point indicates the benefit-cost ratio. Thus, Scenario 1 is seen to have the best benefit to cost ratio followed by Scenario 3. However, the low position of Scenario 1 on the graph indicates its relatively small magnitude of benefits. Note that the slope of a line through Scenario 3 to either 2, 4 or 5 is less than the slope of the reference dashed line indicating a benefit-cost ratio of 1. That is, the additional costs over Scenario 3 to develop the larger space station capabilities of Scenarios 2, 4 or 5 yields a benefit-cost ratio of less than 1. This is interpreted as receiving less than a dollar's worth of benefits for each dollar of additional cost necessary to expand to the larger system.

SPACE STATION COST BENEFITS
YEARS 1985 - 2000



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STEADY STATE COST BENEFITS
BEYOND YEAR 2000

Estimates of steady state annual benefits and costs are based upon a projection where the Mission Model is assumed to be similar to the five-year period 1996 - 2000 and the space station costs represent its O&M costs following the deployment of its final phase. The comparison of steady state benefits and costs is important since comparisons of the 1985 - 2000 period would not demonstrate the availability of full space station cpabilities while emphasizing its major costs in development and production. This chart provides a comparison of steady state benefits, costs and the benefit cost ratio for each scenario.

Scenario 1 has the highest benefit-cost ratio despite very low levels of benefits and costs. Among the space station scenarios, Scenario 3 has the highest net benefits as well as the highest benefit cost ratio. Scenarios 4 and 5 yield the most total benefits but the scenarios are also the most costly. The steady state benefits and costs for these two scenarios are the same beyond the year 2000 since they are identical in this period.

STEADY STATE COST BENEFITS BEYOND YEAR 2000 BILLIONS OF 1984 DOLLARS

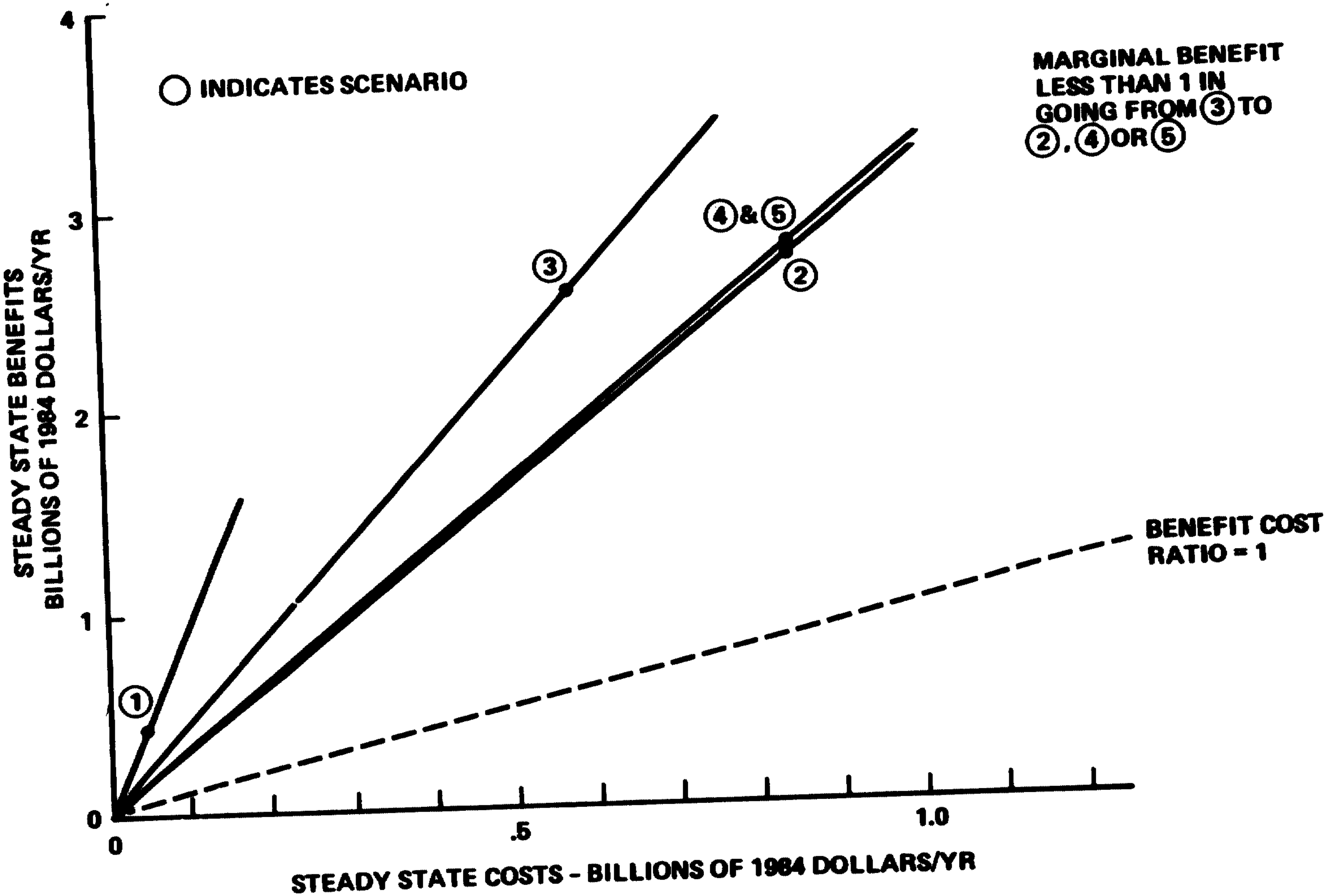
SCENARIO	1985–2000 NET BENEFITS	STEADY STATE BENEFITS	STEADY STATE COSTS	STEADY STATE NET BENEFITS	STEADY STATE BENEFIT COST RATIO
1	$0.7 B	$0.18 B/YR	$0.04 B/YR	$0.16 B/YR	4.5
2	3.7	2.60	0.82	1.78	3.2
3	5.2	2.43	0.57	1.86	4.3
4	3.7	2.66	0.83	1.83	3.2
5	3.4	2.66	0.83	1.83	3.2

SPACE STATION COST BENEFITS BEYOND 2000

This graphic presentation of the steady state benefits and cost illustrates the comparison of both the magnitude of benefits and costs as well as the return of benefits for the cost expended. Scenario 1 has the largest return on benefits as indicated by the slope of the line from the origin. But, the magnitude of the Scenario 1 benefits is much less than those obtained from scenarios that include a space station in LEO. Among the scenarios having a LEO space station, Scenario 3 has the most favorable benefit-cost ratio as depicted by its slope. Of particular note is the slope of a line through Scenario 3 to either 2, 4 or 5 is less than the slope of the reference dashed line representing a benefit cost ratio of 1. Thus, the additional or marginal benefit derived from the expanded space station alternatives is less than the expended costs. The major addition in Scenarios 2, 4 and 5 is a space station in the PEO orbit.

Thus, in both the limited period, 1985 - 2000, and the steady state case beyond 2000, the presence of a PEO station is not justifiable on economic grounds, at least with the Mission Model assumed for this study.

SPACE STATION COST BENEFITS BEYOND 2000



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SUMMARY OF COST BENEFIT RESULTS

The prior analysis has presented various economic data to compare the benefits and costs of each scenario for both the period 1985 - 2000 and beyond the year 2000. Measures of ranking "goodness" for each alternative include magnitudes of benefits and costs as well as the benefit-cost ratio. A qualitative summary of rankings of each scenario is presented in the chart where a completely shaded dot indicates the highest ranking or most favorable scenario relative to the measure and a circle devoid of any shading indicates the lowest ranking scenario. From the standpoint of all measures and the most significant measures combined - net benefits (1985 - 2000), steady state benefits and the two corresponding benefit cost ratios - Scenario 3 has the highest ranking. Scenario 1 ranks high in benefit returns on costs and lowest costs. Scenario 4 and 5 rank favorably when total benefits accrued are considered. Consideration of the qualitative benefits of a manned space station would only serve to further support Scenario 3 and diminish Scenario 1.

SUMMARY OF COST BENEFIT RESULTS

COST/BENEFIT RANKING MEASURE	SCENARIO				
	1	2	3	4	5
NET BENEFITS (1985–2000)	○	◑	●	◑	◔
STEADY STATE NET BENEFITS	○	◔	●	◑	◑
TOTAL SS/SP COSTS (1985–2000)	●	◑	◕	◔	○
STEADY STATE COSTS	●	◑	◕	○	○
TOTAL BENEFITS (1985–2000)	○	◑	◔	●	●
TOTAL STEADY STATE BENEFITS	○	◑	◔	●	●
BENEFIT/COST RATIO (1985–2000)	●	◔	◕	◔	◔
STEADY STATE BENEFIT/COST RATIO	●	◔	◕	◔	◔
PEAK FUNDING	●	◑	◕	◔	○

● MOST FAVORABLE RANKING

CONCLUSIONS

This chart presents the conclusions of the Program Cost and Benefits analysis. The points made are the results of the preceding analysis.

There are sufficient benefits to the Manned Space Station to justify its cost. Scenario 3 is the most cost-effective approach; it consists of a LEO Space Station and Space Platforms at PEO.

Nearly one-third of Space Station costs are due to the STS being used for deployment and O&M. Once the Space Station is fully established there will be surplus benefits in steady state operation.

The cost for the initial Space Station from 1985 - 1990 is $5.4 billion. The peak funding is $1.3 billion.

CONCLUSIONS

- **MANNED SPACE STATION IS WELL SUPPORTED BY SOCIAL, PERFORMANCE AND ECONOMIC BENEFITS**
- **THE MOST COST EFFECTIVE ARCHITECTURE:**
  - **LEO SPACE STATION**
  - **PEO SPACE PLATFORMS**
- **SPACE STATION COSTS ARE HIGHLY DEPENDENT ON SPACE TRANSPORTATION COSTS**
- **SPACE STATION WILL PROVIDE MAJOR BENEFITS IN THE YEARS BEYOND 2000**
- **INITIAL SPACE STATION COSTS:**
  - **TOTAL 1985 - 1990 $5.4B**
  - **PEAK: $1.3B**